Effects of Fire on Flora

A State-of-Knowledge Review
National Fire Effects Workshop
Denver, Colorado
April 10-14, 1978

United States
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Prepared for the Forest Service
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PREFACE

Recent changes in Forest Service fire management policy make it clear that resource managers today need a great deal more information on the physical, biological, and ecological effects of fire. They will need information on fire behavior and fire effects as a basis for analyzing the benefits, damages, and values of various fire management alternatives. Managers must be able to place a value on all resources if they are going to incorporate fire and its effects into land management plans. The Forest Service is committed to the concept that fire management planning has to be a fundamental part of all our planning.

Recent laws and regulations also give additonal guidance for the Forest Service to use in developing land management plans for each unit of the National Forest System. These plans must coordinate outdoor recreation, range, timber, watershed, wildlife and fish, and wilderness resources. Interdisciplinary planning is vital and research must cover the same universe as our planning; therefore, interdisciplinary research is a must.

The effects of fire have been studied since the beginning of organized Forest Service research, but the results are scattered over a wide range of outlets. In addition, research is conducted on the effects of fire under several appropriation line items, and in some instances lacks the interdisciplinary approach needed to make the results as useful as possible to land managers.

The National Fire Effects Workshop was held April 10 through 14, 1978, as a first step in responding to the most recent changes in policies, laws, regulations, and initiatives. One of the major workshop objectives was to prepare a report indicating the current state-of-knowledge about the effects of fire on various resources. These reports formed the basis for pinpointing knowledge gaps. Using this information and input from land managers, priorities for research needed on the effects of fire were established.

Six work groups were established to prepare the state-of-knowledge reports on the following subjects: soil, water, air, flora, fauna, and fuels. Work group members were mainly Forest Service research scientists, but other individuals from the Forest Service, Bureau of Land Management, National Park Service, Fish and Wildlife Service, and Bureau of Indian Affairs also participated.

We hope these state-of-knowledge reports will prove useful to researchers and research planners, as well as to land and fire management planners. Each report will be published as an individual document. A separate bibliography will also be included in this series in an effort to provide a source document for most of the literature dealing with the effects of fire.

INTRODUCTION

Increased emphasis on integrated land management planning and revised fire management policies calls for more definitive and quantified information on the effects of forest and rangeland fire on resource production. To establish appropriate fire protection levels and to plan the use of fire in accomplishing land management objectives, we need to learn how to measure, predict, and interpret biological and ecological responses to the impacts of prescribed fire and wildfire.

Understanding the effects of fire on flora is the key to predicting the impact of fire on resource production in timber, range, wildlife, watershed management, and recreation values. Vegetation is the ultimate integrator for holistic resource management. To understand the effects of fire on vegetation, we must understand the autecology and synecology of all species present in an ecosystem—not just the dominant species or species of interest.

This report on the state-of-knowledge of the effects of fire on flora summarizes pertinent information and describes certain gaps in our knowledge. We organized this report around the major vegetation types as described by Küchler (1966). Table 1 shows the major flora types studied. Where information on understory vegetation existed, we tried to include it. We have undoubtedly overlooked some species and types, but feel we have provided a base upon which we can build. Notable summaries of the role of fire in the ecosystem have been prepared by Ahlgren and Ahlgren (1960), Kozlowski and Ahlgren (1974), and Wright and Heinselmann (1973). Two excellent summaries of autecological and synecological information are Agriculture Handbook 271, compiled by Fowells (1965) and Agriculture Handbook 450, Seeds of Woody Plants in the United States. A paper by Hare (1961) is a good reference for specific information on the effects of heat on plant material.

Table 1.—*Major flora types studied*

Major geographical vegetation areas	Ecoregions-- Bailey (1976)	Potential natural vegetation (PNV)-- Küchler (1966)	Major forest types-- Forest Service (1967)
North Pacific maritime forests	2410, M 2410 M 2110	1-4, 6, 24,25	11-13,18
Forests of the Rocky Mountain west	M 2110, M 3110	11-21	11, 14-19
Sierra coniferous forests	M 2610	5, 7, 8	14, 16, 18
Northern boreal forests of Alaska	1320, M 1310	112-115	
Southern pine forests	2310, 2320	101, 103-106	3, 4
Northeastern coniferous forests	2110	84-88, 97, 99	1, 2
Eastern deciduous forests	2210, 2110, 2320	90-95, 97	5, 6, 8-10
Southern bottomland forests	2310	103	7
Pinyon-juniper woodlands	3130, P3130, M 3110	21	22
Western oak woodlands	M 2620, M 2610, M 3120, 3210	22, 26-28	19, 21
Sclerophyllous hardwoods	M 2620, M 2610, M 3110	29-31	—[1]
Desert	3210, 3220	35-38, 48, 52, 53	—[1]
Prairie grasslands	2610, 3110 2510, 2530	40-48, 54-70	—[1]
Sagebrush-grasslands	3130, P 3130, M 3130, A 3140	32-34, 49-51	—[1]

[1] There are no Forest Service major forest types in this area.

NOTE: In all three classification systems, vegetation types tend to overlap. For example, major forest types 11, 14, 16, and 18 are repeated in different geographic areas.

CONIFEROUS FORESTS
NORTH PACIFIC MARITIME FORESTS

General Description

The maritime forests of the North Pacific cover the rugged strip of terrain between the ocean shore and the crest of the coastal mountain system—the Coast Ranges in Alaska and British Columbia and the Cascade Range in Washington and Oregon. They also occupy a narrow coastal "fog belt" and scattered high mountain sites in northern California. The entire maritime forest area extends along 2,500 miles of the Pacific Slope spanning the latitudes northward from about 36° N to 62° N and then extending westward from longitudes 122° W to 153° W (figs. 1 and 2).

At its northwestern end, the maritime forest area contains scattered Sitka spruce *(Picea sitchensis)*, which are slowly invading the subarctice shrub and grasslands on Kodiak Island (Griggs 1934). Eastward along the south-central Alaskan mainland, this forest area is a narrow, broken strip of Sitka spruce, western hemlock *(Tsuga heterophylla)*, and mountain hemlock *(T. mertensiana)* extending from water's edge to between 1,000 and 1,500 feet elevation (Arno 1966).

Southeastward from south-central Alaska along the Pacific Slope, the maritime forest area gradually widens, and the list of tree species becomes more diverse, with giant western redcedar *(Thuja plicata)* and coast Douglas-fir *(Pseudotsuga menziesii)* becoming major forest components (figs. 3 and 4). In southern British Columbia and Washington, the maritime forest area extends about 100 miles inland from the Pacific and its inlets, covering almost all the terrain between sea level and 5,000 to 6,000 feet elevation on the west slope of the Cascades. Moreover, the distributions of several North Pacific conifers extend across the coastal mountains near the British Columba-Washington border, forming an inland-maritime forest in southeastern British Columbia, northeastern Washington, northern Idaho, and northwestern Montana.

The North Pacific maritime forests reach their best development under the wet, cool climate along the Pacific Slope from southern British Columbia to northern Oregon (Cooper 1957, Heusser 1960, Franklin and Dyrness 1973). Large conifers almost totally dominate these forests at all elevations (fig. 5). Nine conifer genera have their largest (and often longest lived) specific representatives here—and sometimes their second and third largest as well—*Abies, Picea, Pseudotsuga, Pinus, Chamaecyparis, Thuja, Sequioa, Libodedrus,* and *Tsuga* (Franklin and Dyrness 1973).

Southward along the Pacific Slope from central Oregon to northern California, the lowland maritime conifers become restricted to a narrow coastal strip known as the "fog belt," which culminates in the magnificent redwood *(Sequoia sempervirens)* forests of northern California. Maritime mountain conifers occur only sporadically southward in moist, high-elevation sites in northern California, whereas most of the forest above the redwood "fog belt" is dominated by a new set of species, characteristic of the drier California habitats to the south.

Climate is the chief factor responsible for the development of North Pacific maritime forests. The forests are characterized by cool to moderate temperatures, high humidity, frequent fog or cloudiness the year around, and high annual precipitation. Subalpine forests are even more moist and cool, with extremely heavy winter snowfall. From southern British Columbia southward, a midsummer drought situation becomes increasingly common, especially inland from the immediate coastline. Conditions favorable for large wildfires develop briefly every few years during a severe drought. Strong, dry east (foehn) winds occasionally blow into the western portions of Oregon and Washington, causing severe fire conditions. Thunderstorms are uncommon (USDA 1941), but tend to be concentrated in certain years and over mountainous terrain (Morris 1934a). Violent windstorms occur occasionally during the winter months and sometimes blow down extensive areas of forest, especially near the coast (e.g., the Columbus Day storm of 1962).

Figure 1

North Pacific Maritime Forests

Figure 2

North Pacific Maritime Forests - Alaska

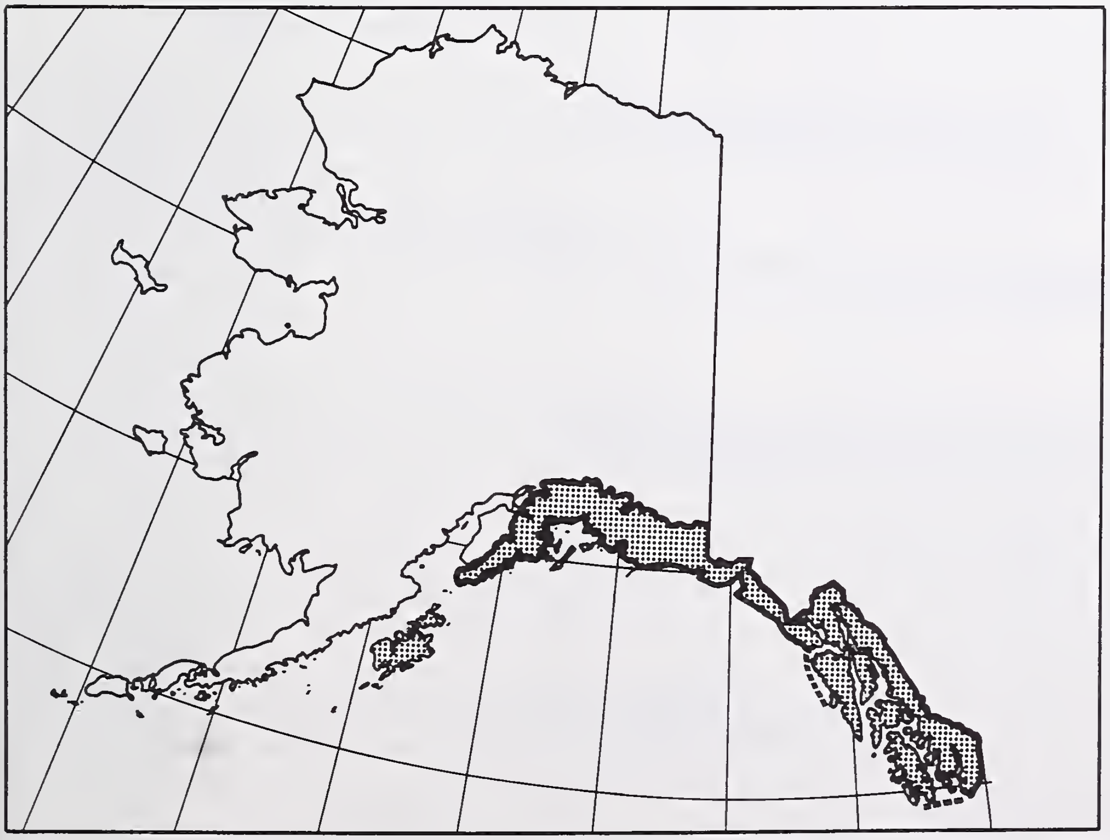
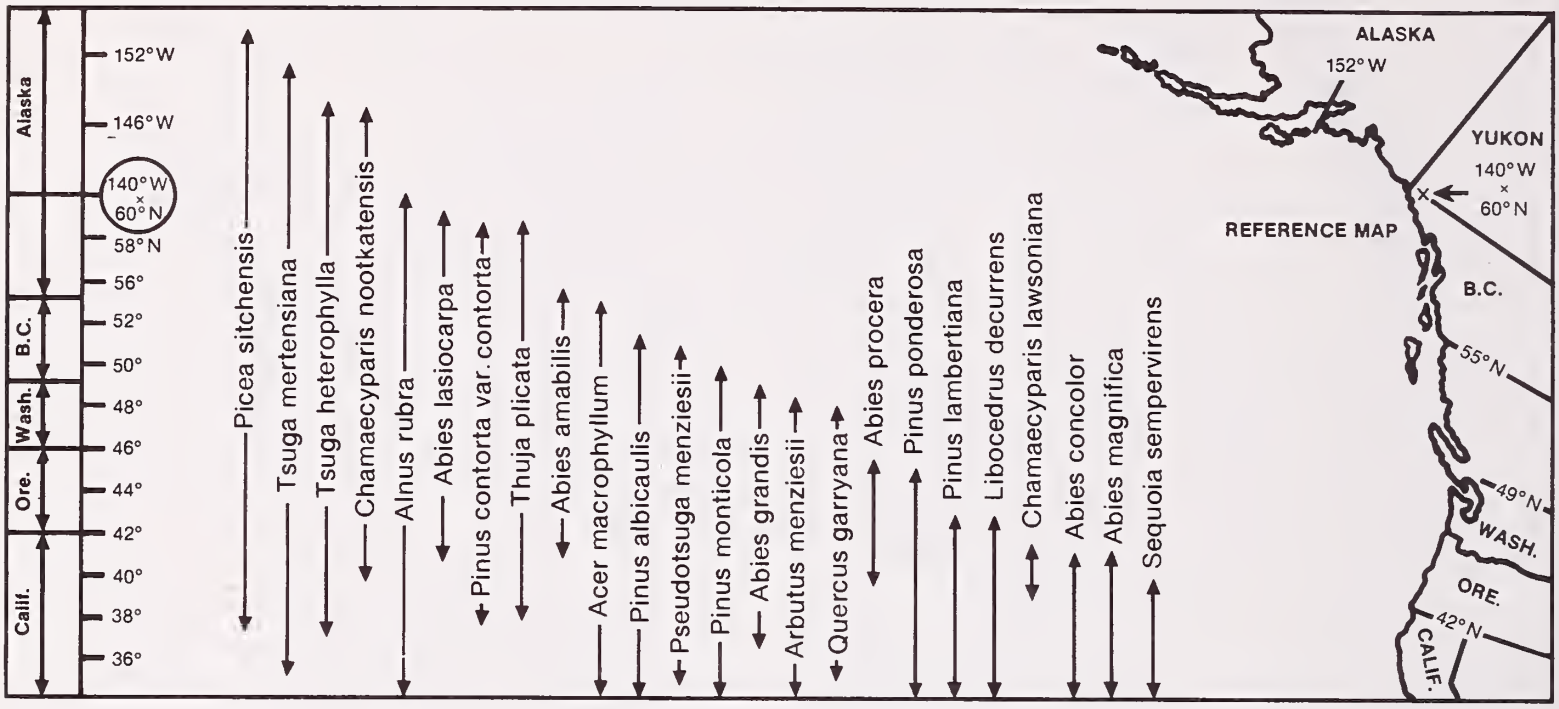


Figure 3

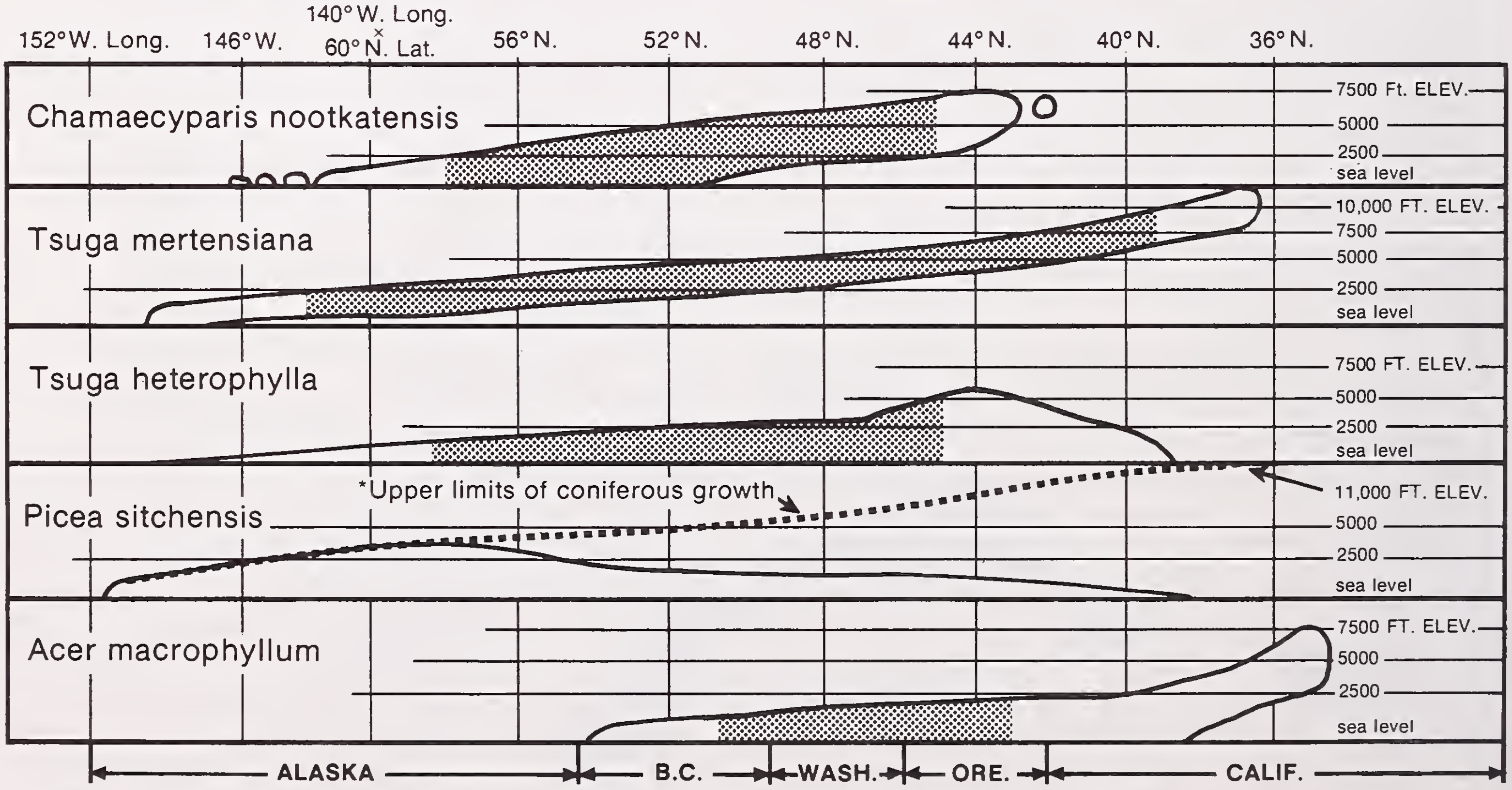
Distributions of Major Forest Trees Along the Seaward Slope of the Pacific Coast Mountain System[1]



[1] This transect begins (top, left) in south-central Alaska (152° W. longitude) and progresses eastward and then southward ending in northern California. Each tree's distribution is indicated by an arrow, which lines up with the scale on the left. The map (right) serves only as a reference for the longitudes and latitudes shown on the scale.

Figure 4

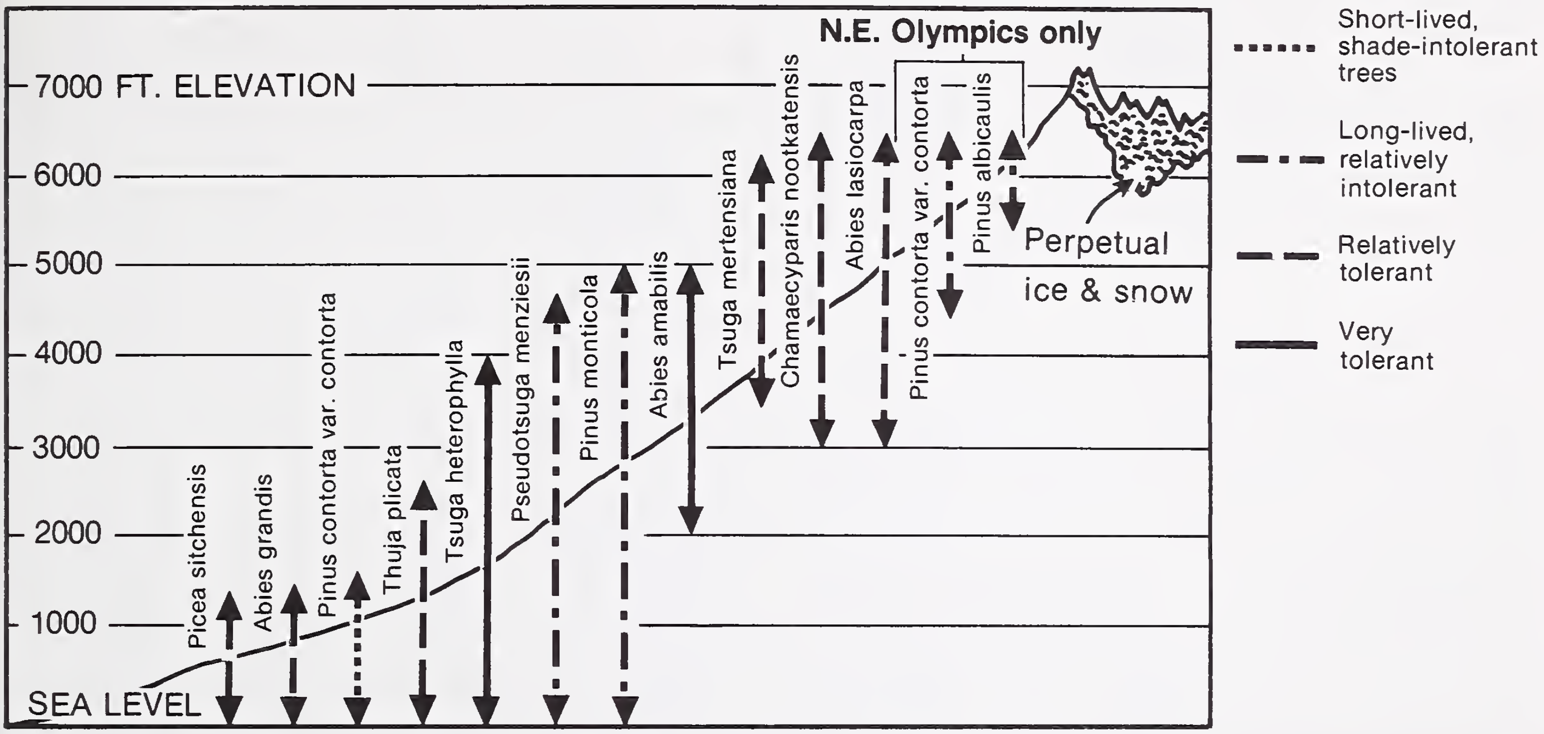
Elevational Distribution of Various Trees Along the Seaward Slope of the Pacific Coast Mountains[1]



[1] Shaded portions represent the area where each species is most abundant in the forest communities.

Figure 5

Generalized Distribution of Coniferous Forest Trees (Overstory Species) in Olympic National Park, Washington[1]



[1] Arrows indicate the usual altitudinal range of each species as well as its relative shade tolerance (from Arno 1966 and Franklin and Dyrness 1973).

Autecology

The tree species are generally adapted to survival and perpetuation in a regime characterized by stand-replacing fires occurring at very long intervals. Table 2 shows fire resistance of most of the major tree species. However, major fires in the maritime forests often kill most trees regardless of their resistance. All species can be killed by crown fire and excessive scorching of foliage. Thin-barked trees often die from cambium heating. Shallow-rooted trees may die from root charring. Additionally, trees are vulnerable (in varying degrees) to insect and disease mortality following injury by fire. Regeneration of most trees is aided by their light, winged seeds, which can be transported one-fourth of a mile or farther by wind (Fowells 1965). Some conifers, including Douglas-fir, have seeds that ripen within burned cones (Isaac 1943, Lyon and Stickney 1974). Franklin and Dyrness (1973) and Fowells (1965) provide some autecological information regarding the different regeneration patterns of major tree species following fire.

In general, red alder *(Alnus rubra)* and Douglas-fir are the principal pioneer tree species of the lower and middle elevation forests from southwestern British Columbia to northwestern California. Thus, red alder and Douglas-fir often dominate the first postfire generation, but an understory of tolerant tree species often develops almost simultaneously. The tolerant tree species that can function as a pioneer dominates when intolerant species fail to gain initial control of the site. Other major tree species that are relatively intolerant of shade and are thus benefited by distrubance are noble fir *(Abies procera)*, lodgepole pine *(Pinus contorta, vars. murrayana* and *latifolia)*, shore pine *(P. contorta, var. contorta)*, and Oregon white oak *(Quercus garryana)* (Franklin and Dyrness 1973). All other major trees in the Northern Pacific maritime forests are relatively tolerant of shade.

Table 2.—*Relative fire resistance of major trees of the North Pacific maritime forests (modified from Flint 1925, Starker 1934, Fowells 1965, and Arno 1977)*

Species	Thickness of bark of old trees	Root habit	Resin in old bark	Tolerance		Relative inflammability of foliage	Degree of fire resistance
				Branch habit	Stand habit		
Sequoia sempervirens	Extremely thick	Medium	Little	High and moderately open	Dense	—[1]	Very high
Pseudotsuga menziesii	Very thick	Deep	Moderate	Moderately low and dense	Moderate to dense	High	High
Quercus garryana	Medium	—[1]	Very little	Moderately high and open	Moderately open	Low	Moderate
Thuja plicata (Sensitive, but tenacious)	Thin	Shallow	Very little	Moderately low and dense	Dense	High	Moderate
Pinus contorta var. *contorta* and var. *murrayana*	Thin	Variable	Abundant	Moderately high and open	Moderately open	Medium	Moderately low
P. monticola	Medium	Medium	Abundant	High and moderate	Dense	Medium	Moderately low
Abies grandis	Medium	Shallow	Very little	Low and dense	Dense	High	Moderately low
A. magnifica	Medium	—[1]	Very little	Low and dense	Dense	High	Moderately low
A. procera	Medium	Medium	Very little	High and dense	Dense	High	moderately low
Tsuga mertensiana	Medium	Medium	Very little	Low and dense	Dense	High	Low
Heterophylla	Medium	Shallow	Very little	Low and dense	Dense	High	Low
Picea sitchensis	Very thin	Very shallow	Moderate	Moderately high and dense	Moderate to dense	Medium	Low
Abies amabilis	Thin	—[1]	Moderate	Moderately high and dense	Dense	High	Low
A. lasiocarpa	Very thin	Shallow	Moderate	Very low and dense	Moderate to dense	High	Very low

[1] No data available.

Vegetational adaptations to fire are outlined in some detail by Lyon and Stickney (1974). Their discussion includes the inland maritime forests of northern Idaho (western hemlock climax), which are compositionally similar to some of the coastal western hemlock-Douglas-fir forest. They state that a majority of shrubs and herbs resprout following crown destruction by fire. (This also applies to broad-leaved trees and redwood on the coast.) Additionally, seeds of some species require heat treatment before germination (e.g., *Ceanothus* spp.), while other species (e.g., *Epilobium, Salix*) have wind-dispersed seeds.

Synecology

Sitka Spruce-Western Hemlock Forest (Küchler 1966: Type 1 and Alaska Type 1)

The Sitka spruce-western hemlock forests are confined to the immediate coastal lowlands from southcentral Alaska to southern Oregon, where mean annual precipitation exceeds 60 inches. Principal tree species are Sitka spruce, western hemlock, and western redcedar, all of which are shade tolerant. South of Alaska, coast Douglas-fir often seeds into sites, after forest fires and then survives 700 years or longer (Franklin and Dyrness 1973, Martin et al. 1974). Spruce and western hemlock may also seed into the burned site. They grow more slowly than Douglas-fir but gain dominance first in the understory and then in the overstory canopy after several centuries without disturbance. Hemlock is slower growing but more tolerant than spruce and thus increases in relative abundance with advancing succession. Most of the hemlock and spruce regeneration in mature stands occurs on rotting logs.

These forests are luxuriant and highly productive, often with a thick humus and litter layer, dense undergrowth of tall shrubs, and very heavy biomass accumulations. Fires are very infrequent, but sometimes severe when they do occur. Martin et al. (1974) estimated that average fire-free intervals are in excess of 150 years. The abundance of stands greater than 400 years old, prior to the advent of logging, suggests that the average fire-free interval was a few centuries.

Fire rarely occurred in Alaskan stands prior to 1900, primarily because of wet conditions and lack of an ignition source (Noste 1969). Noste expressed concern about the modern threat of people-caused fires.

Succession following fire is either to conifers or to a red alder-tall shrub community (e.g., *Rubus spectabilis, Sambucus racemosa*, and *Vaccinium* spp.), which may delay establishment of conifers (Franklin and Byrness 1973). If and when conifers do get established, they benefit from the increased soil nitrogen brought about by red alder.

Western Hemlock - Douglas-fir Forest (Küchler 1966: Type 2)

The western hemlock - Douglas-fir forest type is the most extensive in the coastal northwest south of Alaska. It includes dry forests where Douglas-fir is the potential climax and moist forests where it is seral to hemlock. This type occurs at low to middle elevations (up to about 3,000 feet in western Washington) from British Columbia to the Klamath Mountains of northern California.

This forest type is bordered on the west by coastal lowland forests of spruce-hemlock or redwood. To the east, it adjoins the moist subalpine forests of the Cascades and British Columbia Coast Range. Average annual precipitation is as low as 16 inches in the rainshadow of the Olympic Mountains in the areas dominated by Douglas-fir and Pacific madrone *(Arbutus menziesii)*. At the other extreme within this type, 100 inches or more of annual precipitation occurs in cove sites in the Cascade Mountains, where western hemlock, western redcedar, and long-lived seral Douglas-fir dominate mature stands. Lesser amounts of several other conifers also occur. Generally, in this type, in Washington and southern British Columbia on sites where annual precipitation is 35 inches or more, Douglas-fir is seral to western hemlock and redcedar.

Martin et al. (1974) suggested that average fire frequencies for this type are between 50 and 400 years. Schmidt (1970) documented age classes of Douglas-fir in an area on Vancouver Island and suggested that large fires occurred every century or two prior to European settlement. Evidently fires destroyed extensive stands during extreme burning conditions. Scattered mature Douglas-fir (which often have a 6-inch thick layer of protective bark) that survived have scars from these ancient fires. Such fires were probably much more frequent in the late 1800's and early 1900's because of intentional and careless use of fire by European settlers (Morris 1934b). Although these forests are generally drier than those in the spruce-hemlock, silver fir-Douglas-fir, or mountain hemlock types, fuels dry out only briefly if at all during most summers. Still, severe burning conditions occur every few years. Fires often start in heavy logging slash and are hard to control.

The most detailed successional work has apparently been done in the forests of western Oregon (Franklin and Dyrness 1973), although Miller and Miller (1976) reported on early succession following wildfires in northwestern Washington. Succession varies greatly among the various associations, but the following sequence of stages often occurs (Franklin and Dyrness 1973): An initial herb-dominated stage (e.g., *Senecio* and *Epilobium*) for one or a few years gradually replaced by a tall shrub stage (e.g., *Acer circinatum, Rubus, Ceanothus,* and *Salix*); this overtopped by a broad-leaved tree stage (e.g., red alder, bigleaf maple *(Acer macrophyllum)*); succeeded by a Douglas-fir-dominated forest; in turn replaced by a hemlock-dominated forest. Several of the primary pioneer species such as *Senecio, Epilobium,* and *Ceanothus* are nearly restricted to burned sites. Red alder and/or Douglas-fir usually seed in soon after fire, although persistent alder communities sometimes develop, especially after repeated burns.

Pacific Silver Fir-Douglas-fir Forest (Küchler 1966: Type 3)

The Pacific silver fir-Douglas-fir forests make up the midelevation forest belt of the Olympic Mountains as well as on the western slope of the British Columbia Coast Ranges and the Cascades in Washington and Oregon. The belt extends down to relatively low elevations on Vancouver Island. This type has a colder, wetter, and snowier climate than the hemlock-Douglas-fir forest, which borders it below. Mountain hemlock-subalpine fir *(Abies lasiocarpa)* forests occur above it.

A common successional sequence is Douglas-fir or noble fir or both becoming established soon after wildfire or logging. This community is succeeded by Pacific silver fir *(Abies amabilis)*, which becomes the climax dominant after perhaps 500 to 700 years without distrubance, often accompanied by western or mountain hemlock.

Early stages in forest succession have not been studied in detail. However, major undergrowth dominants after fire or clearcutting are generally species that were present in the stands prior to distrubance, such as, *Vaccinium* spp. and *Xerophyllum tenax* (Franklin and Dyrness 1973)

Mountain Hemlock-Subalpine Fir Forest (Küchler 1966: Type 4)

The mountain hemlock-subalpine fir forest types extends from the Alaska panhandle southward at increasing elevations through the Oregon Cascades. It occupies the coldest and snowiest of the maritime forest zones. Mountain hemlock is a major climax component throughout. Subalpine fir becomes a codominant from southern British Columbia to west-central Oregon. Pacific silver fir and Alaska-cedar *(Chamaecyparis nootkatensis)* are also prominent forest components throughout much of this forest type, although silver fir does not usually ascend to timberline as do the other three species (Arno 1966). Lodgepole pine, shore pine, western white pine, *(Pinus monticola)*, and whitebark pine *(Pinus albicaulis)* also occur locally in this type. Shasta red fir *(Abies magnifica* var. *shastensis)* replaces silver fir in southern Oregon and northern California.

Forest development on burned areas is often slow. In some cases persistent communities of *Vaccinium* spp., *Xerophyllum, Sorbus* spp., and *Spiraea* have been created by repeated burning (Franklin and Dyrness 1973). *Alnus sinuata* also forms persistent communities, especially on snow-avalanche sites. Fields of *Vaccinium membranaceum* productive for huckleberry picking have developed after fires in some areas of the Washington and Oregon Cascades.

Successional sequences of tree species vary geographically. On most sites, the climax species also function as pioneers; however, on relatively dry subalpine sites in the Oregon Cascades, lodgepole pine *(Pinus contorta* var. *murrayana* often develops first.

Redwood-Douglas-fir Forest (Küchler 1966: Type 6)

Redwood forests extend as a narrow band (broken into scattered units at the southern end) at lower elevations along the coastal fog belt from extreme southern Oregon past San Francisco. They are a southern extension of the North Pacific maritime forests occupied by the massive, long-lived, endemic redwood (Zinke 1977). Douglas-fir is the principal dominant and associate of redwood throughout this type. Tanoak *(Lithocarpus densiflorus)*, a shade-tolerant tree, often dominates the understory.

Redwood occupies a relatively broad range of habitats within the fog belt. On relatively wet sites, grand fir *(Abies grandis)* and western hemlock (reaching their southern range limits here) are associated with Douglas-fir and redwood.

Successional sequences for several types of redwood zone forests have been presented by Zinke (1977). When these forests are clearcut, a herbaceous layer emerges but is soon overtopped by ferns (e.g., *Pteridium aquilinum* and *Polystichum munitum*), shrubs (e.g., *Rubus* spp., *Holodiscus discolor,* and *Gaultheria shallon*), and in turn by tree sprouts (tanoak, Pacific madrone, and redwood) and Douglas-fir seedlings. Within a few decades, conifers overtop broad-leaved species. If a stand-destroying fire occurs, the tall shrub *Ceanothus thyrsiflorus* becomes abundant in the pioneer community along with the trees. Since tanoak, western hemlock, and western redcedar are more shade-tolerant associates, redwood is not considered to be the potential climax dominant in a strict sense. However, its superior height and longevity (1,000 or more years) combined with its high resistance to fire, its ability to sprout vegetatively from cut or burned stumps, and its relative shade tolerance vitually ensure its continued presence under natural conditions.

Fritz (1931) analyzed fire scars on old-growth redwoods in a small stand in Humboldt County and concluded that at least 45 wildfires had occurred in the preceding 1,100 years. Most of these were apparently set by Indians and kept the understory open; however, fires also allowed decay to increase in overstory trees.

Oak-Arbutus-Douglas-fir Forest (Küchler 1966: Types 24 and 25)

Oak-arbutus-Douglas-fir forests are mixed broad-leaved - needle-leaved forests that occur in the dry interior valleys of western Oregon and on the driest sites in northern Puget Sound, where they are bordered by moist western hemlock-Douglas-fir forests. They also occupy the interior valleys of northwestern California just inland from the redwood-Douglas-fir forests. This zone represents a transition between North Pacific maritime forests and drier California oakwoods-sclerophyllous shrub communities.

Substantial site differences within this group of habitats complicate understanding of their successional relationships. In addition, agricultural and residential land-use patterns have been superimposed on much of the type, especially in Oregon. Evidently, much of the zone was maintained as a subclimax open oak forest or even an oak savanna by periodic fires set by Indians and early settlers (Habeck 1961, Thilenius 1968, Zinke 1977)

Twentieth-century fire suppression practices have evidently been responsible for both an increase in all tree cover and advancing succession toward domination by Douglas-fir and grand fir on the relatively moist sites.

Oregon white oak, Pacific madrone, bigleaf maple, and Douglas-fir are the principal components of stands in the Willamette Valley and northward. Northwestern California and southwestern Oregon stands have in additon, golden chinkapin *(Castanopsis chrysophylla)* tanoak, canyon live oak *(Quercus chrysolepis)*, interior live oak *(Q. wislizeni)*, and California-laurel *(Umbellularia californica)*.

Fire Characteristics

Fire occurred infrequently throughout most forest types in the maritime forests. Most fires were small and probably of little ecological significance. However, large stand-replacing fires occurred at long intervals (Schmidt 1970, Martin et al. 1974), except in the oak-arbutus-Douglas-fir forest and locally in redwood and Douglas-fir forests at low elevations where historic fires were largely caused by Indians (Weaver 1974) and confined to the ground. Generally, in the North Pacific maritime forests, presettlement, fire-free intervals were 100 years or longer. Maritime forests in Alaska and wet forests in Canada and the northwestern United States in the Sitka spruce-western hemlock, Pacific silver fir-Douglas-fir, and mountain hemlock-subalpine fir types may well have burned only rarely, at intervals of 500 years or longer. In mountainous areas, fire frequency is related to topographic position. Moist valleys and north-facing slopes burn much less often than ridgetops and south-facing slopes.

Fires in the oak-arbutus-Douglas-fir zone may have occurred at intervals comparable to those for ponderosa pine *(Pinus ponderosa)* forests east of the Cascades (5-25 years). Dry areas of the western hemlock-Douglas-fir zone may have burned at 50-to 150-year intervals, often leaving variable amounts of surviving Douglas-firs, some of which have datable fire scars.

Fires probably came in all sizes depending upon initial burning conditions and changes in the weather (Fahnestock 1977, Pickford et al. 1977). Critically dry burning conditons are reached only briefly in mid- to late-summer every few years in most of these types, and lightning is generally uncommon except over the high mountains. Indian-caused ignitions apparently augmented lightning fires, especially in the Puget Sound Trough, Willamette Valley, and other relatively dry valleys (Weaver 1974, Plummer 1900, Fritz 1931). Many large destructive fires at lower elevations accompanied the period of settlement, land-clearing, and early logging (1840-1940). In recent times, there have been increasing numbers of accidental fires, most of which are effectively suppressed. Extensive use of fire to dispose of logging slash occasionally results in large fires escaping into green forest.

Large fires generally kill most trees through crown fire or bole heating. Thick-barked (especially Douglas-fir) and large-diameter trees (especially western redcedar) often survive in areas of less severe burning. Islands of forest remain unburned on wet sites.

Endangered Species

Little has been written concerning the effect of fire on endangered species in the maritime forests. Some plants that occupy habitats where fire was relatively frequent are fire dependent (e.g., *Ceanothus* spp.). Over 300 threatened and endangered species are listed for Oregon and Washington in the Smithsonian Institution's Red Book. Some of these are undoubtedly favored by fire, but detailed information on this has not been published. In contrast, some endangered species that occupy habitats seldom visited by fire may be poorly adapted to regeneration after burning. Several threatened and endangered species are undoubtedly associated with sites that escape burning (marshes, tidal areas, bogs, and rocky alpine or periglacial sites).

Management Implications and Research Needs

Often, in hilly or mountainous areas, fires create a mosaic of stands differing in composition, structure, and age (Weaver 1974). Fire has a pronounced short-term effect, such as loss of nitrogen and perhaps subtler long-term effects upon nutrient cycling in maritime forests (Bollen 1974 and Rothacher and Lopushinsky 1974). The long-term effects, especially, need to be elaborated both for prescribed burning of slash and for wildfires.

Alnus rubra, A. sinuata, and *Ceanothus* spp. often invade burns and enhance soil nitrogen, which subsequently improves site quality for conifers (Franklin and Dyrness 1973). Weaver (1974) pointed out that the great Douglas-fir forest that European settlers found and valued so highly owed its very existence to large wildfires. Modern foresters have attempted to develop vigorous new stands of Douglas-fir and other preclimax species by simulating fire's historic role. Thus they have applied and tested prescribed fire and mechanical approaches for wildfire hazard reduction (slash disposal) after logging and for site preparation (baring mineral soil) (Morris 1970, Muraro 1971, and Lafferty 1972). Klinka (1977) made general recommendations for proper use of prescribed fire (in conjunction with logging) by ecosystem type in southwestern British Columbia.

It must be recognized that the consequences of fire occurring in logging slash, where the overstory has been removed (allowing drying of fuels) and the ground has been disturbed, differs from that of wildfire in natual stands. Knowledge of the effects of prescribed fire and fire substitutes on logged sites is of great importance in resource management and requires additonal research.

More detailed knowledge is also needed concerning fire history and the ecological role of fire in each North Pacific maritime forest type. (More information is available for forests of the inland West, including the Sierra Nevada, and the Southeast.) Because fire's historical role as a vegetation and nutrient recycling agent is not well defined, the existence of persistent shrubfields on productive forest sites is a problem that cannot be adequately evaluated on an ecological basis. The direct roles of wildfire and prescribed burning in nutrient cycling (Bollen

1974), and in erosion and water quality (Brown et al. 1973, Rothacher and Lopushinsky 1974) need attention. Fire's indirect role in nutrient cycling as the agent instituting vegetation-caused nutrient changes (e.g., nitrogen fixation by fire-induced *Ceanothus* and *Alnus*) also needs detailed evaluation.

Fuel accumulation and succession of vegetation after fire in all forest types need better documentation. Fuel accumulation after logging and the potential of prescribed fire to reduce hazardous fuels have been measured in western hemlock-Douglas-fir and Pacific silver fir-Douglas-fir forests by Morris (1970). However, the fuel accumulation-hazard question (Fahnestock 1977) cannot be placed in ecological perspective because patterns of fuel succession and means of recycling fuels (including logging residues) have not been comprehensively examined (Wilson and Dell 1971, Dodge 1972, Martin and Brackebusch 1974). Better knowledge of fire's historic and potential roles in nutrient and residue cycling is necessary to evaluate fuel management techniques on ecological and economic bases (Dell 1977). One such technique is the use of prescribed fire in standing timber.

FORESTS OF THE ROCKY MOUNTAIN WEST

General Description

The Rocky Mountain West forest area covers the Rockies and the east slopes of the Cascades and Sierras—the eastern halves of Oregon and Washington, Idaho, Montana, Wyoming, western South Dakota, Colorado, Utah, Nevada, Arizona, and New Mexico (fig. 6). This area can be divided into two broad forest zones—the Rocky Mountain and the inland maritime.

The coniferous forests found in this area range from warm-dry pine forests to cold subalpine forests of spruce-fir. Many classifications are available for these forests, ranging

Figure 6

Forests of the Rocky Mountain West

from very broad, such as Bailey's ecoregions (Bailey 1976), to very detailed delineations, such as Daubenmire and Daubenmire (1968) or Pfister et al. (1977). The "potential natural vegetation" types described by Küchler (1966) are the primary description units used here. They are fairly broad but are still definitive. Included in these discussions will be vegetation types described in table 3.

With but few exceptions, these forests grow on mountainous terrain. Climates range across a continuum of temperature and moisture combinations from warm to cold and dry to moist. In general, the northern forests experience dry summers while those in the southern Rockies receive more frequent summer rain. Both the upper and lower limits of the forest zones occur at increasingly higher elevations from north to south.

Fire has played an important role in all of the mountain forests and some people speculate that not a single square foot has escaped the path of fire over the millenia.

Table 3.—*Küchler's potential natural vegetation types of the Rocky Mountain and inland maritime zones*[1]

Type No.	Potential Natural Forest Type	Major Tree Components	Occurrence
11	Western ponderosa pine	Ponderosa pine *(Pinus ponderosa)*	Oregon, Washington, Idaho, western Montana
16	Eastern ponderosa pine	Ponderosa pine	Eastern Montana, northeastern Wyoming, western North and South Dakota, northwestern Nebraska
17	Black Hills pine	Ponderosa pine	Black Hills of South Dakota and Wyoming
19	Arizona pine	Ponderosa pine	Arizona
18	Pine/Douglas-fir	Ponderosa pine Douglas-fir *(Pseudotsuga menziesii)* Blue spruce *Picea pungens)* Limber pine *Pinus flexilis)*	Southern Rocky Mountains
12	Douglas-fir	Douglas-fir Western larch *(Larix occidentalis)* Lodgepole pine *(Pinus contorta)* White fir *(Abies concolor)* Blue spruce White spruce *(Picea glauca)* Ponderosa pine	Northern Rocky Mountains and Washington
15	Western spruce-fir	Subalpine fir *(Abies lasiocarpa)* Engelmann spruce *(Picea engelmannii)* Lodgepole pine Douglas-fir	Northern Rocky Mountains and Washington.
20	Spruce-fir-Douglas-fir	Blue spruce White fir Douglas-fir	Southern Utah and Northern Arizona
21	Southwestern spruce-fir	Engelmann spruce Corkbark fir *(Abies lasiocarpa* var. *arizonica)*	Southern Rocky Mountains and Arizona
14	Grand fir-Douglas-fir	Grand fir *(Abies grandis)* Douglas-fir Western larch Western white pine (Pinus monticola)	Idaho, eastern Oregon, and Washington
13	Cedar-hemlock-pine	Western redcedar *(Thuja plicato)* Western hemlock *(Tsuga heterophylla)* Western white pine Grand fir Western larch Douglas-fir Ponderosa pine	Northern Rocky Mountains

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[1] Trees occupy the dominant position in these forests but characteristic shrubby, herbaceous, and grassy species are associated with the trees. For details on these important portions of the flora, consult Küchler (1966) or more detailed local flora classification publications.

Autecology

The wide range of coniferous and associated understory vegetation species of these mountain forests defies simplified autecological descriptions. However, the following generalized fire relationships may help define fire effects in these forests.

After a fire, conifers in these forest zones reproduce only by seed, even though some conifers such as subalpine fir can reproduce by layering in an undisturbed forest. Some of these conifers produce at least some seed annually, but most are cyclical with good seed crops at 3- to 10-year intervals and lesser crops in the intervening years.

Conversely, associated understory vegetation has more possibilities after a fire. It reproduces from sprouts and rhizomes, from seed stored in the soil, such as *Ceanothus*, or from seed dispersed in other ways.

Fire produces conditions favorable to nearly all conifers in these mountain forests by reducing competition, releasing nutrients, and reducing duff depths. However, seral species are generally better adapted than climax species to capitalize on these conditons. In additon, seral species usually have the advantage of better fire resistance, seeding habits, and seedling establishment and growth than their climax companion species.

For example, in the Douglas-fir forests of the Northern Rockies, fires create favorable seedbeds for regenerating all the conifers. On a relative scale, fire favors ponderosa pine, western larch, and lodgepole pine over Douglas-fir. The thick bark of all these species—with the exception of lodgepole pine—provides survival adaptation and allows them to regenerate on the favorable seedbeds. However, since Douglas-fir is more shade tolerant than its associates, it retains longer crowns. Long crowns, coupled with a high foliage flammability, make Douglas-fir more susceptible to "crowning" during ground fires than its associates in this type.

Mature trees of both larch and ponderosa pine can withstand fairly severe fires because of their thick bark. In addition, both can be prolific seed producers, resulting in a new crop of seedlings on the receptive seedbeds produced by the fires.

Although lodgepole pine is susceptible to fire because of its relatively thin bark, its serotinous cone habit permits it to regenerate even though the parent tree may have been killed in the fire (Lotan 1976).

Synecology

All of these forests steadily progress toward a vegetational climax, but fire and other disturbances can interrupt this cycle. As a result of these disturbances, seral plant communities are increased and climax communities decreased. Increasing fires result in increasing seral components of the forest. Some tree species can occupy a seral poition in one forest type and a climax position in a different forest type. Some species are nearly always climax —others nearly always seral. As a general rule the more shade tolerant the conifer, the greater is its susceptibility to damage and mortality from fire. Successional changes in the tree component of the forest are accompanied by corresponding changes in the understory shrub, herb, and grass components of the forest. Several of Küchler's types will be combined in the following discussion for reasons of simplification where fire and successional patterns are similar.

Ponderosa Pine Forest (Küchler 1966: Types 11, 16, 17, and 19)

Ponderosa pine types are those forests where ponderosa pine is climax and where associated conifers are essentially absent. These types should not be confused with those forests where ponderosa pine is seral (e.g., some Douglas-fir forests). Grass and shrublands generally abut the lower, drier edge; and at the upper edge, Douglas-fir and some of the true firs merge with the pine. Ponderosa pine forests occupy drier sites than any other commercially valuable type.

Fire is the major factor affecting successional patterns in these ponderosa pine types with ground fires every 5 to 25 years. Because ponderosa pine is the only major conifer in these potential vegetation types, fire does not result in a conversion to other tree species. Instead, it creates uneven-aged stands of ponderosa pine in open, park-like stands (Weaver 1974). Young ponderosa trees are killed by ground fires, but the older and larger trees with their thick bark are fire resistant (Wellner 1970). Although scarred repeatedly, older and larger trees can survive, and their scars attest to the frequency of fire in the area (Arno 1976). Ironically, the same fire that consumes some of the younger trees also creates a favorable seedbed for the establishment of new seedlings.In this continual game of "survival of the fittest," some of the young trees are missed or survive the frequent ground fires and develop thick bark, which provides their own protection against fire.

Where frequent ground fires have persisted in these ponderosa pine forests, "crown" fires are rare. However, fire has been excluded throughout most of the ponderosa pine forest in the last half century, resulting in densely stocked young stands with a corresponding increase in fuel loads. Increased fuel, the dense young stands with more continuous and interlacing crowns, and the "laddering" effect of small to medium to tall trees have increased the threat of the once rare "crown" fire.

Douglas-fir Forest (Küchler 1966: Types 12 and 18)

Douglas-fir is the primary climax species in these forest types. Its associate conifers range from relatively simple combinations with ponderosa pine and some blue spruce and limber pine in the southern Rockies to more complex ecological associations with ponderosa pine, western larch, blue and white spruce, lodgepole pine, and white fir in the northern Rockies. Aspen *(Populus tremuloides)* is also found as an associate in this zone.

Douglas-fir forests generally occur just above and are more mesic than the climax ponderosa pine zone. In the northern Rockies, the climax ponderosa pine type is often absent and Douglas-fir forests abut shrub and grasslands.

In the absence of any major disturbance such as fire, this forest type eventually succeeds toward increasing stand components of Douglas-fir at the expense of its more intolerant associates. Periodic fires, on the other hand, tend to favor the more fire-adapted and less tolerant species such as western larch (Schmidt et al. 1976), ponderosa pine, and lodgepole pine.

Absence of fire in these types commonly results in the development of dense thickets of Douglas-fir. These thickets, with their low, dense crowns, can provide the fire "ladders" that can result in conflagrations. These same Douglas-fir thickets are apparently providing conditions suitable for buildup of defoliating insects in some areas.

Spruce-Fir Forest (Küchler 1966: Types 15, 20, 21)

The same successional story can be told for the spruce-fir forests as for the Douglas-fir forests, except some species have been added, some do not occur, and some have changed their climax and seral roles.

These forests exist at high elevations. At the upper elevational limits, they abut the alpine and at the lower, warmer limits they merge with the Douglas-fir climax forests. Growing seasons are short, snow depths are generally high, and cold-wet conditions usually prevail (LeBarron and Jemison 1953). This results in the gradual buildup of fuels because forest litter accumulates faster than it decomposes in these cold-wet conditions.

In the absence of fire or other major disturbance, these forests succeed toward increasing proportions of the "true" firs such as subalpine fir, white fir, and corkbark fir at the expense of the spruces, Douglas-fir, and lodgepole pine. Interestingly enough, Douglas-fir plays a seral role in the spruce-fir types. Lodgepole pine, with but few exceptions, is seral. Seral and nearly pure lodgepole pine stands cover vast acreages in these spruce-fir types throughout the Rockies. Fire has undoubtedly been the major factor in maintaining lodgepole pine as the predominant species over these vast areas. Its serotinous cone habit enables it to seed prolifically after fires and thus maintain itself (Lotan 1975 and 1976). Meanwhile, lodgepole pine's counterparts of spruce and the true firs are not as well adapted. Both are thin-barked, retain long flammable crowns, and as a result have a low degree of fire resistance.

Therefore, fires in these forests favor lodgepole pine, give Douglas-fir somewhat of an edge because of its thick bark, and inhibit spruce and the true firs. Interestingly, this corresponds directly with the shade tolerances of these species.

Inland Maritime Forest (Küchler 1966: Types 13 and 14)

Ecologically diverse and complex, inland maritime forests occur primarily in the northern Rockies. Northern Idaho serves as the epicenter. Although generally 300 to 500 miles inland, these forests have many of the Pacific maritime influences, which result in moist, generally mild temperature conditions. Although relatively limited in extent, these forests are highly productive. Because of the maritime influence, these forests generally occur at elevations where one would expect ponderosa pine forests to predominate in the northern Rockies.

Succession follows patterns similar to those described for other Rocky Mountain forest types. Here, however, there is a richer flora and somewhat more complex changes over time than other Rocky Mountain forests. Without fire or other major disturbance, succession eventually leads to western redcedar and western hemlock, or to grand fir where cedar and hemlock are absent (Wellner 1965). Best known in these types is the western white pine. Both it and western larch are seral species, owing their very existence in this zone to fire. Without fire, both will occur only sporadically if succession proceeds to the ultimate climax of grand fir or the cedar-hemlock forests.

Fire Characteristics

Fire has been one of the most dynamic ecological forces governing the flora of the entire Rocky Mountain chain. Although natural fire frequencies vary considerably by forest types, nearly every square foot of this vast area probably has burned sometime in the past. Relatively short intervals between fires can be expected to result in fires of low intensity because forests have accumulated less fuel to burn. Generally, as fires become more infrequent, heavier fuel loads accumulate, and fire intensity increases.

Fire frequencies in ponderosa pine forests probably occurred naturally at intervals of 5 to 25 years. Fires occurring this often were no doubt low-intensity ground fires maintaining the open park-like stands of the ponderosa pine woodlands.

Natural fire frequency ranges widely in the Douglas-fir zone. Where ponderosa pine is a major associate, fire frequencies of about 10 years (Arno 1976) are common. However, in the cooler sites, 10- to 30-year frequencies are more likely. It should be recognized that fires originating in the lower and drier sites frequently burn into these more mesic areas. Fire damage in this zone is likely a function of the length of time since the last fire—the longer the period, the greater the probabilities of conflagration. Wellner (1970) felt that fires in this zone caused slight to heavy damage, but Arno's (1976) data in the Bitterroot area of Montana suggest that fire damage usually was not severe under "natural" conditions where fires burned more frequently.

Conflagrations appear to be the general rule in the spruce-fir type especially in the seral lodgepole pine (Brown 1975). Although no extensive data are available, severe fires most likely occur every 100 to 500 years (Brown 1975). However, recent evidence indicates that low ground fires do occur at 30- to 40-year intervals in some areas (Arno 1976 and Gabriel 1976). Perhaps the most common reason for the conflagrations is the combination of a hot, dry season and an extensive fuel accumulation either due to insects, such as the mountain pine beetle (*Dendroctonus ponderosae* Hopk.) (Amman 1975) and disease (Hawksworth 1975), or due to slash from logging. These fuels are often ignited by fires that originate in the lower drier forests. Even severe fires do not destroy all trees in the spruce-fir forests but usually leave islands that can serve as a seed reservoir for restocking the area. As mentioned earlier, seeds stored in serotinous cones of lodgepole pine give it an advantage over its associates. However, the true firs, Douglas-fir, and spruce are generally good seed producers and disperse their seeds for considerable distances, with the light-seeded spruce having a distance advantage.

Although decomposition rates are fairly rapid in the moist-temperate inland maritime forests, accumulations of litter and duff are still excessive, resulting in fuel buildup. Extensive fires, such as those of 1910, burned vast acreages of these forests and resulted in extensive tracts dominated by the seral species of western larch; western white pine; and, in some cases, lodgepole pine. Interestingly, Douglas-fir is seral in these forest types and is favored by fire. Although the widespread even-aged forests that occur in this inland maritime area are the result of vast, intense fires, there is some evidence (Marshall 1928) that ground fires periodically burned without killing all the trees. Of the three major climax species, grand fir and western redcedar are ranked medium in fire resistance, while western hemlock is ranked low (Wellner 1970).

Management Implications and Research Needs

Prescribed burning has been used successfully throughout most of the range of ponderosa pine forests for reducing fuel loads to prevent conflagrations, cleaning up slash after harvesting, preparing seedbeds, and in some cases for thinning the stands and in others for stimulating production of palatable grasses and shrubs (Weaver 1967, Schubert 1974, Davis et al. 1968, Pfolliott et al. 1977, Wright 1978). There do not appear to be many arguments against the use of prescribed burning in ponderosa pine forests, and there is much to be said in its favor. However, a half century of intensive fire control has resulted in some fairly explosive fuel and stand conditions that will require knowledge and expertise not yet available for all stand and burning conditions.

Prescribed fire is commonly used in Douglas-fir forests for reducing fire hazards after harvesting and simultaneously preparing sites for regeneration. Several major studies in the northern Rockies (Beaufait et al. 1975, Norum 1976, Shearer 1975, Lyon 1971) have been conducted to refine prescribed burning methods and define conditions for regenerating these forests. Considerable work has also been accomplished in Oregon and Washington (Hall 1974, Martin et al. 1974, Tiedemann and Klock 1974, Weaver 1967) and in the southern Rockies (Kallander 1969, Lindenmuth 1960). The major problems in the use of prescribed fire in Douglas-fir forests now lie in those areas where fire has been excluded for a long period of time. Here, fuel has accumulated and the stands are "laddered," presenting difficulties in using prescribed fire.

Prescribed fire has been used extensively for many years in the inland maritime forests to dispose of slash after harvesting as well as to prepare a good seedbed. Heavy accumulations of up to 100 tons of slash per acre make many of the harvested areas a veritable powder keg. Adding to this accumulation are aires of insect-and disease-killed timber, resulting in an enormous threat of conflagration.

Managers have also turned to prescribed fire in subalpine spruce-fir forests and for reducing duff and litter layers. Duff reduction facilitates natural and artificial regeneration of such species as lodgepole pine and spruce. One of the major problems with using prescribed fire in these subalpine types is the cold moist condition during most of the year. Ideal burning conditions are infrequent. To use fire effectively, the manager has a short burning period. If burned when it is too wet one does not get a "good" burn. If burned when conditions are explosive, one runs a risk of "losing" a fire.

In summary, our greatest opportunity to use fire effectively is in the climax ponderosa pine and Douglas-fir forests. It is in these forests where most research and management applications have been underway. Refinements are needed, however, in both how-to-do-it and in the biological realm of determining not only *what* happens, but also *what* we want to accomplish with fire. Much work needs to be done in the spruce-fir and the inland maritime zones for the same reasons already mentioned. However, the knowledge base appears substantially less and, in most cases, the problems more complex.

The opportunities appear great for using fire for vegetation manipulation, whether it be improving big-game forage production, favoring certain species of trees and shrubs, reducing competition for tree seedlings, removing segments of the forest that provide the media needed by insects and disease, or merely letting succession follow a more natural pattern in wilderness.

Fire has always been a part of the western forests and probably always will be. We must come to understand it better and learn to use it more effectively.

SIERRA CONIFEROUS FORESTS

General Description

The Sierra coniferous forest types extend up the slopes of the various mountain ranges of California (fig. 7). Within the lower zone of this area, ponderosa pine *(Pinus ponderosa)* is gradually replaced by white fir *(Abies concolor)*. Intermediate between these species is the mixed conifer forest, which additionally includes incense-cedar *(Libocedrus decurrens)*, sugar pine *(Pinus lambertiana)*, Douglas-fir, *(Pseudotsuga menziesii)*, and giant sequoia *(Sequoiadendron giganteum)*.

Above the ponderosa pine and white fir mixed forests are the red fir *(Abies magnifia)*, lodgepole pine *(Pinus contorta* var. *murrayana)*, and Jeffrey pine *(Pinus jeffreyi)* forests.

Below timberline in most of the mountains in California is the subalpine forest. It consists of mountain hemlock *(Tsuga mertensiana)*, whitebark pine *(Pinus albicaulis)*, western white pine *(Pinus monticola)*, foxtail pine *(Pinus balfouriana)*, limber pine *(Pinus fexilis)*, and western juniper *(Juniperus occidentalis)*. The forest varies from widely spaced trees up to 75 feet tall to short, dense thickets near timberline.

Autecology

In the gradient from ponderosa pine to white fir, the various species display a range of shade tolerance and fire tolerance. Ponderosa pine is the most intolerant of shade and requires an open and shallow seedbed for regeneration. Giant sequoia requires a mineral soil seedbed before new trees can germinate. White fir, on the other hand, can become established in shaded areas and in deep duff layers. The other species are intermediate in their shade tolerance.

Ponderosa pine and giant sequoia can tolerate moderate amounts of fire because of their thick bark. The pine needles form flammable fuel beds, which are conducive to burning practically every year. White fir has a compact fuel bed that burns less often.

Figure 7

Sierra Coniferous Forests

Red fir occurs immediately above the white fir forests. The trees regenerate in small openings where moisture becomes available after the death of one or more mature trees. These small openings, as well as larger ones, can be caused by fire, windthrow, or insect epidemics. Jeffrey pine is similar in its autecology to ponderosa pine. Cold temperatures are assumed to separate the two pines. Lodgepole pine communities above the red fir are open with little understory and litter. Lodgepole pine's tolerance for moisture allows it to become established and survive in sites that would be too wet for red fir or Jeffrey pine.

The subalpine species are limited by moisture and temperature. Fire does not play an important part in their reproductive strategies.

Synecology

The interactions of the tolerance the species have for shade, fire, and moisture determine the ultimate mix of the forest. Moisture is important at both the upper and lower ends. In the intermediate area, fire and shade interplay to create a mosaic of species. Frequent fires tip the balance to pine and sequoia, while less frequent fires favor incense-cedar and fir.

Moisture, temperature, and fire play important roles in determining the distribution of the dominant species in the upper mountain forests. Without periodic fires, lodgepole stands would probably succeed to red fir forest. Moisture, however, plays a more important part.

Fire Characteristics

In the lower boundary of the Sierra coniferous forests, fires occur every 3 to 13 years. Although an intense fire is possible, fires in the lower boundary are generally of low intensity. In the more moist upper forests, fuel and weather conditions are such that fires occur less often. When they do ignite, however, they are usually of greater intensity than those below. Periods of from 8 to 25 years between fires are common.

Fires seldom occur in subalpine forests although it is possible for entire dwarfed stands to be consumed just below the timberline. Most fires are low in intensity and spread slowly through sparse fuels.

Effects of Fire

Most fires in the Sierra Nevada forests do not result in universal burning over the entire soil surface. Surface litter layers are burned lightly; and, in areas of concentrated heavy fuels, hot burning of the soil surface occurs. These intensely burned spots provide seedbeds for several species, especially giant sequoia.

Soil nutrient levels are temporarily increased after burning in these forests. Erosion seldom occurs as a result of fire since large areas are seldom burned with an intensity hot enough to expose large expanses of soil.

The most dramatic ecological effect of fires in the Sierra coniferous forests is the maintenance of fire tolerant species over shade tolerant species. The reproductive strategies that have evolved in the presence of fire allow these species to be perpetuated under a regime of periodic, low-intensity fires.

Threatened and Endangered Species

Few woody species found in the Sierra Nevada Mountains are threatened or endangered. Most rare species are annual or perennial forbs. On occasion, their habitats will have to be protected from natural or people-ignited fires. More often, however, their habitats are a result of the dynamic state of the ecosystems as influenced by fire. Management of these systems with fire will do more to preserve critical habitats than any other management strategy.

Management Implications and Research Needs

The closer a forest system is managed in harmony with the natural processes by which it evolved, the more successful that management will be. If the species we wish to manage are the same species favored by fire, then it is wise to recognize fire as an integral part of our management programs. This is important not only from a silvicultural point of view but also from an integrated fire management prospective.

Quantitative vegetative data are lacking for the Sierra Nevada as a whole. Specific information is needed on the relative fire and shade tolerances of the various species and their abilities to regenerate. The interrelationships of fire with other ecosystem factors such as insects and disease must also be studied.

NORTHERN BOREAL FORESTS OF ALASKA

General Description

The northern boreal forests of Alaska consist mainly of open, slow-growing spruce interspersed with occasional dense, well-developed forest stands and treeless bogs. The trees tend to be small in stature, unlike those in the closed, fast-growing forests farther south in the boreal forest. This area is called by the Russian term "taiga," which means "tiny sticks."

The taiga covers a major part of Alaska (fig. 8), extending from the Brooks Range south to the interface with coastal forests and eastward to Canada. The western boundary reaches a maritime treeline close to the Bering and Chukchi Seas (Viereck 1973). About 32 percent is forested. Only a portion can be classified as commercial forest (table 4).

Forests on warm, well-drained sites consist of white spruce *(Picea glaucas)* stands mixed with paper birch *(Betula papyrifera)* or aspen *(Populus tremuloides)*. Black spruce *(Picea mariana)* dominates poorly drained sites, those underlain by permafrost, and most north-facing slopes. Wet sites also support tamarack *(Larix laricina)* along with black spruce. The many rivers and floodplains support extensive stands of balsam poplar *(Populus balsamifera)* and black cottonwood *(P. trichocarpa)*. Grasslands, meadows of sedge, large bogs, some alpine tundra, and thickets of brush are interspersed among the forest areas.

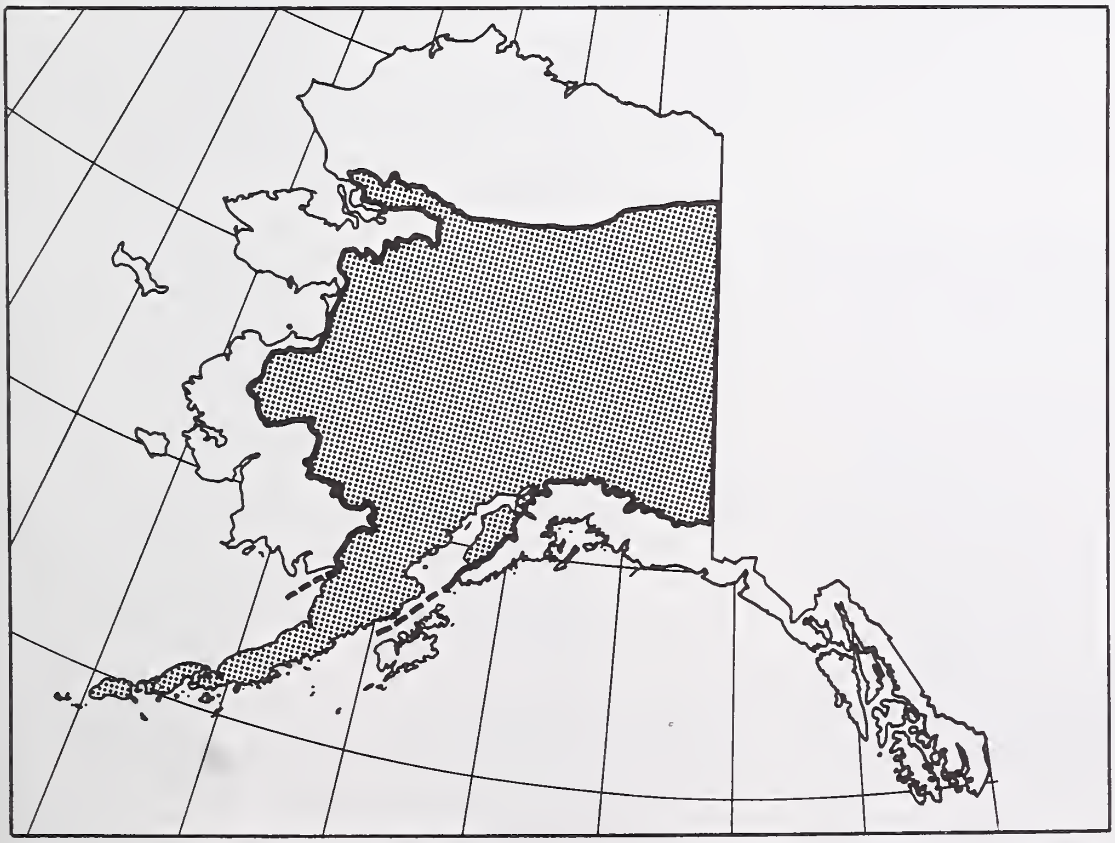
Within the forests, especially the more open stands, the understory vegetation consists of willows *(Salix* spp.), resin birch *(Betula glandulosa)*, many ericaceous shrubs, *Claudonia* lichens, feather mosses, and sphagnum mosses (Viereck 1973). Thickets of alder *(Alnus* spp.), willow, and resin birch are common near tree lines.

One bog type that deserves special mention because of the great area it covers is a tussock sedge type with considerable sphagnum mosses and abundant low ericaceous shrubs.

Some grasslands occur, especially on windy sites. These are dominated by *Calamagrostis canadensis* and *Festuca altaica*.

Figure 8

Northern Boreal Forests of Alaska (Taiga Zone)



Work is progressing on the establishment of phytosociological groupings to describe habitat types. However, there has not been an evaluation of this work, to say nothing of mapping such associations. Therefore, this summary has been organized by describing effects of fire on the various strategies of reproduction.

Autecology

The reproductive characteristics of Alaskan trees and shrubs play a key role in the rate of recovery following fires. Rapid regrowth occurs from vegetative reproduction. Sprouting of these trees and shrubs originates from roots, rhizomes, and buds on the lower stem. Intense burning can reduce, and in some cases eliminate, the ability of trees and shrubs to reproduce vegetatively. In these instances, regeneration must be from seed on the site or from unburned forests adjacent to the burn. Seed regeneration grows more slowly than vegetatively produced regeneration. The reproductive characteristics of most common trees and shrubs are summarized in this section and table 4.

Table 4.—*Commercial forests including trees and tall shrubs.*

Species	Source of reproduction	Remarks and general response characteristics
Quaking aspen	Roots that occur at organic matter/mineral soil interface or in mineral soil. Usually not deeper than 2 to 5 inches in mineral soil.	Produces root suckers on roots of all sizes. Density of suckers will depend on amount of aspen in pre-burn forest. One- to 3-year-old stands may contain 50,000 to 100,000 stems. On good sites in the interior forest and in the absence of severe browsing, dominant stems can be up to 15 feet tall at age 3. Relatively vigorous stands up to at least 150 years old produce abundant suckers.
Paper birch	Sprouts originate from buds at base of tree (root collar).	Sprouts occur on trees of all sizes. Ability to sprout will depend on fire intensity and stand age. Preliminary results of studies on upland sites indicate that in stands that are 120 years or older, sprouting will occur on fewer than 50 percent of trees. Early growth is similar to aspen.
Balsam poplar	Reproduces from roots and buds at base of tree.	Species most abundant on river flood plains. However, where it occurs on upland sites it appears to regenerate almost as vigorously as aspen and birch.
White spruce Black spruce Tamarack		Vegetative reproduction immediately following fire does not occur. These species, especially black spruce, reproduce vegetatively by layering. This is a process in which lower branches become overgrown with moss and eventually produce roots. The uncovered tip of the branch forms a tree.
Willow	Sprouts originate from buds at stem base.	Ability to resprout in all stages of vigor, this includes the most decadent old clumps in black spruce that appear to have little living tissue. Intense burning can completely destroy willows.

Vegetative Reproduction

Much of the following information is drawn from work by Zasada (1971). It was compiled and organized as part of a state-of-knowledge workshop for fire resource advisors, given in March 1978 at Fairbanks, Alaska.

Vegetative reproduction is of critical importance to rapid recovery of vegetation following disturbance. Intense fire or severe disturbance can result in significantly slower rates of recovery and increased potential for soil movement. Although there are not studies comparing seedling growth and growth of vegetatively produced regeneration, vegetative regrowth is thought to be at least two times greater than seedling growth. In aspen, where observations are available, growth of dominant suckers during the first year can be five to eight times greater than that of seedlings on the same site.

Reproduction From Seed

Low Shrubs

Relatively little information is available regarding seed reproduction and periodicity of seed crops for these species (table 5). Seed regeneration of low shrubs is not normally a significant factor in rate of recovery immediately after fire. The reason for this is that vegetative parts are mostly destroyed.

Because mature seed-producing plants of these species are either totally destroyed or killed by fire, no immediate source of seed is available. However, because of rapid vegetative reproduction and improved environmental conditions, abundant flowering and seed production can occur 3 to 5 years after burning. Seed reproduction can also be important for species that have seeds buried in the organic layers and mineral soil. A major source of specific information is Agriculture Handbook 450, *Seeds of Woody Plants in the United States.*

For convenience, the information in this section is divided into species with fleshy fruits (berries) and those with dry fruits.

Low Shrubs With Fleshy Fruits (Berries)

Fruits and seeds of these species are consumed in large quantities by various animals. In the process, seeds may be destroyed, cached, or passed through the animal and dispersed. Predation by animals is important in the dispersal of these seeds.Because berries are heavy, they would not move far from the plant if dependent on wind or gravity. Animals assist in moving seed long distances from the parent plant.

The unaltered seeds of these species have a seedcoat, which is frequently described as hard, stony, and/or impermeable. This type of seedcoat makes these seeds highly resistant to various weather and biological variables. Because of this resistance, these seeds can exist for long periods of time in the soil and organic layers. Germination can occur after a disturbance such as fire. Raspberry appears to be the best example of an Alaskan species regenerating from buried seed.

It is difficult to generalize about seedbed conditions for low shrub species. Certainly, many of them germinate and grow on mineral soil. However, because of their importance as a food for predators and their relatively resistant seedcoat, they are often found germinating in organic matter and specific microsites (e.g., animal feces, seed caches). The important thing to remember is that organic matter is a poor germination medium because it rapidly dries out and heats up when exposed to the sun. When kept moist, organic matter can be a good seedbed. This frequently is the case an inch or more below the organic surface.

Maturation of these species' seeds occurs in late summer or fall. Characteristics of some of these species are given in table 6.

Low Shrubs With Dry Fruits

Seeds of these species are small (up to 5,000,000 seeds/lb). Seedcoats are thin and membraneous—markedly different from those of the fleshy-fruited low shrubs. Size and shape of seed indicate that wind is the dispersal agent. Each fruit produces many seeds.

There has been little experience with the germination of seeds and seedling establishment of these species. However, the size of the seed and nature of the seedcoat suggest that they are more similar to trees and tall shrubs than to fleshy-fruited low shrubs. Thus, a mineral soil seedbed that provides a more stable supply of moisture and less temperature fluctuation than organic matter is probably necessary for optimum germination and early seedling growth.

Germination of these species occurs fairly rapidly under normal temperature regimes after

Table 5.—*Seed regeneration and periodicity of low shrubs in the northern boreal forests of Alaska.*

Species	Relative depth of underground parts	Source of reproduction	Remarks and general response characteristics
Prickly rose	Deep	Extensive rhizomes in the lower part of organic layers and mineral soil.	Produces new shoots at intervals along the rhizomes after fire, as well as from base of fire-killed above ground stem. Spreads rapidly after disturbance.
Highbush	Deep	Extensive rhizomes mainly in lower organic layer and mineral soil.	Similar to rose.
Buffaloberry	Deep	Rhizomes extending to mineral soil.	
Currants (all species)	—[1]	Rhizomes extending to mineral soil.	
Raspberry	Medium-deep	Extensive rhizomes in mineral soil.	Can spread very rapidly following disturbances. Frequently originates from seed following disturbance of mature forest.
Blueberry	Medium	Depending on species, may have buried stems or rhizomes. Occur mostly in organic layers in black spruce type.	Initial sprouting after fire occurs at the base of fire-pruned aerial stems. Sprouts from buried stem become evident later than those from fire-pruned aerial stems.
Labrador tea	Medium	Buried stems.	Response in interior Alaska similar to blueberry.
Beauvered spirea	—[1]	Sprouts at base of fire-pruned stems. Reported to spread from rhizomes.	Occurs in multistemmed clumps.
Rusty menziesia	Medium	Rhizomes and basal sprouting.	
Shrub birches	—[1]	Sprout from base of fire-pruned stems.	
Red-osier dogwood	—[1]	Rhizomes and basal stem sprouts.	
Bunchberry	Shallow-medium	Rhizomes located in organic layer.	
Twinflower	Shallow	Rhizomes in organic layer and at organic/mineral interface.	Appears to be adversely affected by mineral disturbance of surface organic layers.
Bearberry	Shallow	Rhizomes and layering.	
Lowbush	Shallow	Extensive rhizome system in surface organic layers.	Extensive rhizomes with shoots produced at intervals.
Cloudberry/ Nagoon berry	Shallow	Rhizomes.	

[1] Information on these species is limited. Only the most common species have been included.

winter stratification. If the seed does not germinate during the first or second growing season, it probably loses its viability.

Seeds mature in late summer and fall with dispersal occurring shortly after.

Species included in this group are: Laborador tea *(ledum greenlandicum* and *L decumbens),* Beauverd spirea *(Spirea beauverdiana),* Rusty menziesia *(Menziesia ferruginea),* and Resin birch *(Betula glandulosa).* Table 7 is a useful compilation of reproductive characteristics of some Alaskan trees and shrubs.

The role of fire in Alaskan ecosystems is complex and prominent. Two cases of special interest illustrate the kinds of problems that can occur in Alaskan fire management. The first case involves the burning of caribou winter range. These areas are often poorly drained, wet sites underlain with permafrost. Certain species of fruitcose lichens are preferred by caribou as winter forage. Estimates of 50 to 150 years are given for full recovery of a severely burned lichen mat (Scotter 1967). More recent work by Miller (1976) indicated that the story is much more complicated than that. He suggested that perhaps some fires at long intervals may be needed to maintain lichen production.

Another case involving fire is the cottongrass tussock situation typified by the Seward Peninsula of Alaska. Immense areas of peninsula have burned frequently and as recently as 1977. Reindeer are grazed here, and concern has been voiced regarding loss of range. Yet, the burned areas show rapid recovery and possibly improved palatability. More work is needed to resolve these issues.

Research Needs

Fires in similar vegetation types have been studied. Response of shrubs has not always been consistent from fire to fire in Alaska. One possible reason for this may be the extent to which the organic layer was burned away and the depth of penetration of killing temperatures. If these can be predicted from preburn measurements, shrub management will be much improved. Timing of the fire with regard to seed dissemination may also be a variable. It may be

Table 6.—*Germination characteristics of low shrubs with fleshy fruits.*

Species	Seed/fruit	Germination characteristics
Prickly rose *(Rosa acicularis)*	Single	Appears to require a sequence of winter-summer-winter after seed maturation for germination to occur. A seed crop produced in any given year may require a number of years to germinate even under adequate conditions.
Highbush cranberry *(viburnum edule)*	Single	Germination requirements as or more complex than those of any species in Alaska. Period of cold (winter) followed by warm (summer) results in root development. Seedling shoot initiation (completion of germination) requires another winter.
Buffloberry *(Shepherdia candensis)*	Single	Seeds able to germinate completely summer after maturation.
Currants *(Ribes spp.)*	Single	Germination of some seeds can occur in spring following dispersal. However, seeds may remain dormant for many years.
Raspberry *(Rubus idaeus)*	Multiple	Small number of seeds may germinate the year after dispersal, but may remain dormant for a long period.
Blueberry *(Vaccinium uliginosum* and others)	Multiple	Able to germinate completely the summer after dispersal.
Lowbush cranberry *(Vaccinium vitis-idaea)*	Multiple	Similar to blueberry.
Red-osier dogwood *(Cornus stolonifera)*	Single (maybe 2 embryos in seed)	Capable to germination the summer after dispersal.
Bunchberry *(Cornus canadensis)*	Same as red-osier dogwood	
Nagoon-berry *(Rubus arcticus)*	Multiple	Germination of seeds can occur the summer after dispersal; evidence indicates that seed germinates overseveral years.
Cloudberry *(Rubus chamaemorus)*	Multiple	Similar to nagoon-berry.
Bearberry *(Arctostaphylos uva-ursi)*	Multiple	Germination occurs slowly over a period of years.

Table 7.—*Reproduction characteristics of selected Alaskan trees and shrubs (Zasada 1971)*

Species	Seed bearing age (years)	No. of years between good seed crops	Maximum no. of seeds/plants	Time of seed ripening	Seed dispersal pattern	Distance of seed dispersal (max.)
White spruce *(Picea glauca)*	20-40	2 to 10	100,000-200,000	Aug.-Sept.	Most seed dispersed Sept. through Jan.	200 to 400
Black spruce *(Picea mariana)*	20-40	See "other considerations."	25,000-50,000	Aug.-Sept.	April through September	100-200
Tamaracks *(Larix laricina)*	20-40	3 to 6	—[2]	Aug-Sept.	Similar to white spruce	100 to 200
Paper Birch *(Betula papyrifera)*	10-20	1 to 3	500,000-1,000,000	July-Sept.	Sept. through May	300 to 600
Quaking aspen *(Populus tremuloides)*	10-20	1 to 2	1,000,000+	June	June	Up to several miles
Balsam poplar *Populus balsamifera)*	10-20	1 to 2	1,000,000+	June-July	June to July July	Up to several miles
Willow *(Salis spp.)*						
Disperse seed in summer	4-10	1 to 2	—[2]	June-July	June to July	Up to several miles
Disperse seed in the fall	—[2]	1 to 2	—[2]	June-Aug.	Sept.-Nov.	Up to several miles
Alder	5-10[3]	1 to 2	—[2]	Aug.-Sept.	Sept. through May	100

[1] John Zasada, 1979 personal communication.

[2] No data available.

[3] Age at which seed bearing begins is dependent on whether plant starts from seed or is vegetative in origin.

more true in Alaska than anywhere else that the forest lives in the forest floor. Alter the forest floor with fire, and the vegetation will be altered. Alter it a great deal, and the floral composition may be significantly changed. Fire effects research in Alaska should concentrate on the changes caused in the organic forest floor and the conditions leading to those changes.

This is not to suggest that immediate effects of fire on aboveground vegetation can or should be ignored. Conditions leading to death or damage of trees, shrubs, forbs and grasses, mosses, and lichens must be studied and described if the manager is to be able to make sound decisions on future fires.

Experimental fires and documented wildfires can both be useful. Experimental or "prescribed" fires offer careful preburn inventories, preburn measurements of conditions such as moisture contents, and a selection of seasonal time of burning. Wildfires offer large acreages and various vegetation types, permitting broader study of long-term responses. However, to be soundly useful, the conditions

Means of dispersal	Seedbed preference	Time of germination	Relative growth rate	Other considerations
Wind	Best germination on mineral soil; can germinate and establish on thin organic layers.	Begins in May and can occur through Aug.	Slow	
Wind	Best germination on mineral soil; can germinate and establish on thin organic layers.	Similar to white spruce	Slow	Periodicity similar to white spruce. This is less important because cones are semi-serotinous and seed is held in them 5-10 or more years. In other words, once a tree reaches seed bearing age, it will contain cones of different age with variable amounts of seed.
Wind	Best germination on mineral soil; can germinnate and establish on thin organic layers.	Similar to white spruce	Slow	There is little experience with tamarack growth and reproduction in Alaska.
Wind	Mineral soil	Similar to white spruce	Medium to fast	Seed quality (number of germinable seeds) varies greatly from year to year in birch. Percent of filled seed may be less than 10 in some years.
Wind	Mineral soil	June and July	Medium	Aspen, willow, and balsam poplar do not have male and female flowers on the same tree or shrub. Rather there are male and female plants. All other trees and tall shrubs mentioned in this table have both male and female reproductive structure on the same plant.
Wind	Mineral soil	June and July	Medium fast	
Wind	Mineral soil	June and July	Medium fast	
Wind	Mineral soil	May and June	Slow	
Wind	Mineral soil	Similar to White spruce	Medium fast	

existing when the wildfire occurred must be measured and recorded. This has been rare in the past, but is becoming common practice now.

Perhaps Lutz (1956) summarized it best when he stated that wildfire partially or fully destroys forest communities (in Alaska) and extensively changes the vegetative structure and occasionally the plant-species composition of such communities. Pioneer species of plants that regenerate in or invade burned areas are frequently short-lived in comparison with the long-lived climax species (white and black spruce in the north). Pioneer species tend to produce light, easily disseminated seeds in numbers that favor colonization of burned tracts.

Further studies are needed to describe those conditions and seasons leading to these differential effects of fire on Alaska's flora.

SOUTHERN PINE FORESTS

General Description

The flora of the southern pine forests, which extend from Maryland and New Jersey, southward to Florida, westward to eastern Texas, and northward into Missouri and Tennessee (fig. 9), is rich in species, with some 100 different tree species and probably 8 or 10 times more shrubby, herbaceous, and grassy species. Fire has played an important and often decisive role in shaping the compositon and in controlling succession of this flora. Many species are quite fire tolerant, so fire has had no major impact on their presence.

The southern pine forests are found in six major physiographic areas: the Coastal Plain, the Piedmont, the Appalachian Highlands (including the Blue Ridge and the Valley and Ridge areas), the Cumberland Plateau, the Interior Low Plateau, and the Interior Highlands (including the Ozark and Ouachita Mountains) (Nelson and Zillgitt 1969). These physiographic areas are bisected by major rivers and many smaller streams, forming a mosaic of numerous sites in which the southern pines grow.

This discussion of the southern pine forests is based on Küchler's 1966 map of potential natural vegetation and includes his oak-hickory-pine forest (type 101), southern mixed forest (type 103), pocosin (type 104), sand pine scrub (type 105), and subtropical pine forest (type 106). The effects of fire on the major species in these five forest vegetation types are discussed separately.

Use of Fire and Its Effects

Oak-Hickory-Pine Forest (Küchler 1966: Type 101)

The oak-hickory-pine forest, more commonly called the loblolly-shortleaf pine forest, is the largest timber type in the Eastern United States, extending from southern New Jersey and Maryland southwestward to east Texas and Oklahoma and northward to southeastern Missouri and Tennessee. This forest type occurs in all six physiographic regions and on a broad spectrum of soils.

Figure 9

Southern Pine Forests

Nearly 200 papers have been published on fire effects in this type, including a proceedings of a Forest Service prescribed burning symposium in 1971 in which much of the knowledge on fire effects for this vegetation type in the southeast is summarized. Prescribed fire has been an effective and efficient silvicultural tool for hazard reduction (Cooper 1971), Davis and Cooper 1963, Romancier 1960); for controlling competing vegetation (Bower and Ferguson 1968, Brender and Cooper 1968, Chaiken 1952, Ferguson 1961, Grano 1970, Harrington and Stephenson 1955, Hodgkins 1958, Hodgkins and Whipple 1963, Hodgkins and Watkins 1968, Langdon 1971, Lotti 1956, Lotti et al. 1960, Silker ,1961, Yocom 1972); for preparing seedbeds (Chaiken and LeGrande 1949, Little and Mohr 1963, McNab and Ach 1967, Trousdell and Langdon 1967); for improving quantity and nutrient quality of range forage (Duvall and Hilmon 1965, Halls et al. 1952, Halls and Alcaniz 1971, Lewis and Harshbarger 1976, Wahlenberg et al. 1939); and for managing and improving wildlife habitat (Blair 1968, Cushwa et al. 1966, Cushwa and Reed 1966, Cushwa and Martin 1969, Cushwa et al. 1969, Halls 1973, Komarek 1971). Based on available information of effects of burning on soil properties (Metz et al. 1961, Moehring et al. 1966, Ralston and Hatchell 1971, Wells 1971), Stone (1971) concluded that decreases in site productivity from prescribed burning are not likely for Coastal Plain soils. Prescribed burning reduces severity of annosus root rot on southern pines (Froelich et al. 1978), and burning is now recommended as a preventive measure for annosus root rot (Froelich et al. 1977).

Prescribed burning can effectively influence the composition, amount, and size of the understory vegetation in loblolly and shortleaf pine types in Coastal Plain areas. Less is known about fire effects in this forest type in the Piedmont, the Cumberland Plateau, the Ouachita Highlands, or the Ozark Plateau than in the Coastal Plain. Thus, more work is needed in those regions, especially long-term studies on the effects of burning on vegetation, soils, and site productivity. Because of the many species that occur in association with loblolly and shortleaf pine over their wide range, a great deal more research is also needed to ferret out the effects of burning on the more important species as well as on the rare and threatened ones.

Southern Mixed Forest (Küchler 1966: Type 103)

The southern mixed forest, commonly known as the longleaf-slash pine type, is exceeded in importance in the South only by the loblolly-shortleaf pine type. In the virgin forest, longleaf and slash pine did not occupy the same sites. Longleaf, highly resistant to fire in its seedling stage, maintained itself on drier sites, while slash pine highly susceptible to fire damage in its seedling stage, was confined to wet areas (Langdon and Schultz 1973).

When it comes to prescribed burning, one might say that managers of longleaf pine lead the way. Based on experience with this species it was concluded early that fire was required in the life cycle (Andrews 1917). The benefits to longleaf pine of burning were later found to be related to effectiveness of fire in controlling the brown-spot needle blight disease (Siggers 1934). Since the first observation in the late 19th century that fire had a place in management of longleaf pine, many prescribed burning studies have been carried out, with more than 200 papers being written on fire effects in this vegetation type.

Forage is an important resource of the longleaf-slash pine forests and supports a livestock industry that contributes substantially to the South's economy (Halls et al. 1964). Prescribed burning is necessary to maintain and improve palatability, quality, and availability of grasses, forbs, and other desirable plants for range cattle and wildlife (Duvall and Whitaker 1964, Greene 1935, Grelen and Epps 1967, Grelen and Whitaker 1973, Grelen 1975, Hilmon and Lewis 1962, Lay 1967, Lewis 1964, Lewis and Hart 1972, Stoddard 1935).

One of the continuing problems in managing longleaf and slash pine stands in the flatwoods of Georgia and Florida is how to control the growth of such understory species as sawpalmetto and gallberry (Burton and Hughes 1961, Hough 1965, Hough and Albini 1978, Hughes and Knox 1964). These species are extremely flammable, and when a wildfire occurs, they burn with such intensity that overstory pines are often severely damaged or killed (Sackett 1975). A 3-year winter burning interval is now recommened to reduce fire hazarad from sawpalmetto and gallberry (Sackett 1975).

However, methods of using prescribed fire to control this vegetation, perhaps in combination with mechanical and chemical control measures and other seasons of burning, need further study.

Pocosin Forest (Küchler 1966: Type 104)

The pocosin forest type covers a rather nondescript, broad, flat area of poor drainage resulting in extensive beds of peat and organic soils, forming upland bogs. Several site-type occur within a typical pocosin. Pond pine is the principal tree found in pocosins and is associated with an almost impenetrable jungle of broad-leaved, evergreen shrubs and vines in the understory.

Fires have played an important role in this ecosystem in controlling the understory and in maintaining pond pine in the stand. Pond pine, because it can sprout from the bole, can survive wet-season fires even when severely defoliated (Wenger 1965). Also, its serotinous cones are opened by the heat of fire (Kaufman and Posey 1953), and the burn prepares the seedbed for seed germination. Seedling regeneration usually follows such burns (Crutchfield and Trew 1961, Shepherd et al. 1951). However, dry season fires often eliminate pond pine, and the stand usually reverts to shrubby vegetation and sprout hardwoods (Wenger 1965).

Cane, a grass-shrub, is a common component in the understory of pocosins and furnishes some of the best native grazing in the South (Shepherd et al. 1951), but periodic prescribed fire is required to maintain cane in a productive and highly nutritive condition (Hughes 1957, 1966).

Fires that burn in this type are usually high-intensity fires because of the flammability of the fuels (Taylor and Wendel 1964). Wildfires occur rather frequently in this type and when they do they are difficult and expensive to control. Some prescribed burning has been done in pocosins, but knowledge of fire behavior is limited (Taylor and Wendel 1964). Knowledge of fire effects for this type is scant; more research on fire behavior and effects of fire is needed.

Sand Pine Scrub (Küchler 1966: Type 105)

The sand pine scrub type is confined largely to Florida, occurring outside of Florida only in a small area in southeastern Alabama (Little and Dorman 1952). Two varieties of sand pine—Ocala and Choctawhatchee—are now recognized; the former has serotinous cones and the latter does not (Burns 1973). Stands of the Ocala sand pine have often been regenerated after a wildfire because heat from the fire opens the serotinous cones, and large quantities of seed are released a few days later (Cooper 1951, Cooper et al. 1959). Although fire plays a role in its regeneration (Cooper 1965), sand pine is susceptible to fire damage and subsequent mortality because of its thin bark (Cooper 1973) and the tendency of fires in this type to crown, particuarly during the spring and during years rainfall deficiencies (Hough 1973). Prescription burns in this type have not been as successful as might be expected because of the difficulty of predicting fire behavior (Cooper 1973), which points to the need for further research. However, if this problem could be solved, there is considerable evidence that prescribed fire would have a role in sand pine regeneration (Cooper 1953, Price 1973), although it has not proved as effective as mechanical measures in the preparation of sandhill sites for planting (Burns and Hebb 1972), in improving wildlife habitat (Lewis 1973), in reducing hazardous fuels (Cooper 1973), and in lowering the occurrence of wildfires (Davis and Cooper 1963). Sand pine is now being planted on many sandhill sites; studies are needed to determine the place and effects of fire in such planatations.

Subtropical Pine Forest (Küchler 1966: Type 106)

The subtropical pine forest is restricted to southern Florida, and its extent is limited by subtropical climate and soils (Davis 1943). South Florida slash pine is the dominant species in this type, but this forest differs from any other forest in the continental United States in that the understory has many tropical species of hardwoods, shrubs, and palms (Robertson 1953). In its limited range this type also has about eight plant species that are threatened or endangered; fortunately, many are found within parks and preserves and are thus protected (Little 1976). Prescribed fire has a place in this forest to control the tropical hardwoods if south Florida slash pine is to be maintained in this forest type (Robertson 1953). The Everglades

National Park uses prescribed fire within the park boundaries for this purpose (Craighead 1971), but more research is needed to quantify effects of such burns.

Summary of Fire Effects in the Southern Pine Forest

Fire is an important element in the ecology of southern pine forests; a great deal is known about how fire affects the flora of this region, especially the timber species. Yet in spite of this, there are still many gaps in our knowledge on effects of fire on lesser vegetation (especially the less common, the rare, and endangered species) and associated hardwood species. Prescribed burning in the two principal pine types of the region—loblolly-shortleaf and longleaf-slash—is an operational silvicultural tool, especially in the Coastal Plain. Prescribed burning is used by many landowners to prepare seedbeds, to control understory hardwood competiton, to reduce fire hazard and the risk of wildfire, to control certain tree diseases, and to manipulate range and wildlife habitats.

The South, which in the early days of forestry was criticized for its fire problem, has turned this problem into an opportunity. In doing so, the South, in many respects, has led the way in fire effects research and the subsequent use of prescribed fire. In spite of this, much is yet to be learned about the long-term effects of fire on many sites. The research should move forward in these areas where our knowledge is lacking.

NORTHEASTERN CONIFEROUS FORESTS

General Description

Northeastern coniferous forests are located east of the Great Plains, primarily on three major physiographic divisions (fig. 10): (1) Interior Plains, (2) Appalachian Highlands, and (3) Laurential Upland. The climatic range is broad, being humid microthermal in the north and humid mesothermal in the south. Annual precipitation ranges from about 30 inches in the northwestern range of the Northeastern coniferous forests to 60 inches or more in the southern Appalachians. The range of site conditions is great. There are about 10 major coniferous tree species and many times that number of shrub and herbaceous species found within the northeastern coniferous forests.

Autecology

Conifers of the northeastern forests do not sprout. Jack pine, however, has serotinous cones that may be opened by the heat of fire, making an immediate source of seed available after fire (Cayford 1970, Cooper 1961). Black spruce has the reproductive advantage of persistent, semiserotinous cones that store seed (Heinselman 1974). On many areas, fires after logging destroyed the seed sources of white and red pine and possibly white spruce and balsam fir, because these species do not have serotinous cones.

Brown and Davis (1973) have summarized relative fire resistance of selected tree species of

Figure 10

Northeastern Coniferous Forests

the Eastern United States. This summary provides information on basal bark thickness of mature trees, character of tree crown, character of stands, and rooting habit. Trees were placed in fire resistance groups with red pine listed as resistant; white pine and jack pine listed as moderately resistant; and the spruces, aspens *(Populus tremuloides, Populus grandidentata)*, cedar, and fir listed as least resistant. Balsam fir is rated the least fire resistant on a list of 22 major Northeastern State species by Starker (1934).

Aspen and paper birch (*Betula papyrifera)*, species associated with the northern conifers, produce lightweight seeds, (Fowells 1965). Aspen seed, in particular, can be carried long distances by wind (Fowells 1965). Both species reproduce by basal sprouting, and aspen also reproduces by root suckers (Fowells 1965). It is the absence of fire that favors the increase of balsam fir (Bakuzis and Hansen 1965).

Synecology

The successional trend for these broad coniferous types (table 8) —the pines, the spruce-fir, as well as the aspen-birch where associated with conifers rather than hardwoods—is generally toward spruce-fir. The spruce-fir type will sometimes be replaced by northern hardwoods or balsam fir.

Aspen occupies millions of acres that once were covered with northern conifers—a result of past fires, logging, and land-clearing (Brown and Davis 1973). The successional trend for these stands is generally toward spruce-fir and, where soil and climatic conditions permit, toward northern hardwoods.

On the coarse sandy soils of Wisconsin and Michigan, where pine is associated with oak (principally northern pinoak *(Quercus ellipsoidalis)*, the successional trend is toward oak, with red maple *(Acer rubrum)* included on more mesic sites in Wisconsin (Cox, 1977). In studying remnant virgin stands of northern hardwoods and white pine in Wisconsin, Maissurow (1941) concluded that, without fire or other disturbance, a stand of sugar maple *(Acer saccharum)* with basswoods *(Tilia americana)* included in moist locations would spread over the hardwood soils and many of the pine sites.

Many investigators have inventoried the plants and studied the phytosociology of northern coniferous forest plant communities including trees, shrubs, vines, and herbs—sometimes including lower plants—Pteridophyta, Byophyta, Thallophyta. A few of these investigations will be mentioned, including studies where fire was not directly involved, as those results can be given fire effects interpretations.

Kittredge (1934) described relative abundance of shrubs and herbaceous vegetation under specific forest cover—jack pine, red pine, white pine, and maple-basswood—in Minnesota. Cooper on Isle Royale (1913) and Buell and Niering in Minnesota (1957) studied the shrub and herbaceous vegetation under climax stands of

Table 8.—*Potential natural vegetation types (after Küchler 1966) and major tree species occurring in the Eastern United States*

Küchler type	Major tree species
Great Lakes pine forest—Type 86	**Jack pine** *(Pinus banksiana)* Red pine *(Pinus resinosa)* White pine *(Pinus strobus)*
Great Lakes spruce-fir forest—Type 84	Balsam fir *(Abies balsamea)* White spruce *(Picea glauca)*
Northeastern spruce-fir forest—Type 87	Balsam fir *(Abies balsamea)* Red spruce *(Picea rubens)*
Conifer bog—Type 85	Larch *(Larix laricina)* Black spruce *(Picea mariana)* Northern white cedar *(Thuja occidentalis)*

spruce-fir-birch. Cooper (1913) also studied the confier bog. McRae (1979) summarized responses of trees, shrubs, and herbaceous plants to prescribed burning of jack pine slash. Ahlgren (1970) reported fire effects on shrubs and herbs after burning jack pine slash and control plots in Minnesota. Martin (1959) studied trees, shrubs, and herbs of plant communities in various successional stages in Algonquin Park, Ontario. The study included aspen-birch, pine, spruce-fir, and conifer bog types. Vogl (1964) reported effects of fire on trees, shrubs, and herbs of lowland plant communities in northern Wisconsin. Ohmann and Grigal (1978) studied the tree-shrub-herb community for five growing seasons following fire in northeastern Minnesota virgin forest communities.

Great Lakes Spruce-Fir Forest
(Küchler 1966: Type 84)

The upland spruce-fir forest is not fire prone. However, with drought conditions, potential for high intensity fires exists. Budworm-killed balsam fir may also contribute significantly to fire suppression problems (Flieger 1970, Sando and Haines 1972). In addition, as the jack pine and aspen component increases within the type, the potential for fire increases.

Fire has a place in slash reduction and seedbed preparation for this forest type. This type is not naturally adaptable for underburning, so uses of fire during rotation of the stand are not likely.

Great Lakes Pine Forest
(Küchler 1966: Type 86)

Pine types are not only frequently fire initiated, but are also fire prone. Van Wagner (1970) stated that the most flammable pure stand of any northeastern species is one of red pine when it is growing at high density with a clean floor.

Prescribed fire has been used satisfactorily to remove slash, reduce humus, and control shrub competition, enabling successful jack pine establishment by direct seeding and by seed trees (Ahlgren 1970). Prescribed burning techniques have been developed and described for preparing a seedbed and controlling competing vegetation under white and red pine (Van Wagner and Methven 1978, Methven and Murray 1974). White pine is much more adaptable than red pine to regeneration by natural seeding, according to Van Wagner (1970), who further stated that perhaps the main future source of red pine will be plantations. Hazel *(Corylus spp.)* is a serious competitor for pine regeneration. In northern Minnesota, either a spring or summer fire was found to kill tops of hazel, but summer fires and repeated fires were most effective in obtaining complete kill or reducing vigor and sprouting ability (Buckman 1964). A guide describing techniques for prescribed burning for jack pine regeneration is available (Beaufait 1962).

The scorch height for establishing probable tree mortality and its relation to fireline intensity has been established using red, white, and jack pine and red oak *(Querus rubra)* stands in Ontario, Canada (Van Wagner 1973).

Results are available to guide hazard reduction and seedbed preparation for pine types. These results can generally be used. However, unique local conditions may make application of these guides questionable without further testing.

Northeastern Spruce-Fir Forest
(Küchler 1966: Type 87)

This is not a fire-prone type, but under drought and extreme fire weather conditions high intensity fires are possible. Use of fire during the rotation is not likely, as the type is not adaptable for underburning.

Prescribed fire has been shown to be effective in reduction of heavy slash, following a clearcut in the spruce type of Maine,so that handplanting is possible (Randall 1966).

Stickel and Marco (1936) identified fire injuries as the entry point for insects and fungi on trees of the red spruce cover. type.

Conifer Bog
(Küchler 1966: Type 85)

Fires are infrequent within this cover type, requiring unusual drought conditions when a forest cover is present. Once a stand is established, it is unlikely that fire would serve any positive purpose during the rotation, as the type is not adaptable to underburning.

Fire has been used in northern Minnesota to prepare a seedbed for black spruce reproduction (Johnston 1971) and tamarack *(Larix laricina)* reproduction (Johnston 1973). Fire may be used to reduce logging slash.

Fire Characteristics

The northeastern coniferous forests present at the time of settlement existed because of fire. From a comprehensive study of the Boundary Waters Canoe Area in Minnesota, it was concluded that a natural fire rotation of about 100 years existed before settlement, with some white and red pine stands remaining intact for 150 to 350 years, while some jack pine and aspen-birch stands probably burned at intervals of 50 years or less (Heinselman 1973). Fires rarely occur in the spruce-fir of the Northeast. In general, fires in the northern coniferous forests are infrequent, large, and highly intense.

Effects of Fire and Management Implications

Fire may bring about a number of changes in the environment such as an increase in light at the soil surface, an increase in daily temperature range at the soil surface, earlier development of vegetation in the spring, and earlier desiccation of the upper soil (Daubenmire 1974). Increased soil temperature may, under some circumstances, kill young tree seedlings (Ahlgren 1974).

One possible fire-related problem is the inability of some species to reproduce successfully under themselves because of an allelopathic situation. This could be related to the theory of alternation of species (Spurr and Barnes 1973). The identification of toxic material, its source and its target, and the possible role of fire in neutralizing the toxic situation—either by eliminating certain plants or plant materials or by chemically changing plant materials—should be investigated.

Differential bark thickness and insulating qualities by tree species and tree size are significant to a tree's ability to survive fire. A literature survey of bark characteristics and fire resistance concluded with emphasis on the need for information on the thermal properties of bark (Spalt and Reifsnyder 1962). In his study on bark, Martin (1963) found that density, moisture content, and temperature accounted for most of the variation in thermal properties, regardless of species.

Research Needs

There is a considerable amount of information on the effects of fire on flora for the northern coniferous forests. A major research need is a comprehensive review of applicable knowledge and literature—assembling information into appropriate planning and operational guides where none exist. Additional specific research needs would be identified in the process.

To facilitate multiple-use management, there is need for information on postfire response for entire vegetative communities. Most emphasis has been on the trees. Further studies are needed on the sprouting abilities of species as related to age, size, and other variables. Another need is investigation of the possible role of fire in reduction or elimination of allelopathic situations. Additional research is needed on fire adaption (or susceptibility) of species and physiological processes.

Recognition of the relative fire resistance of species, based on morphological characteristics such as leaf, bud, and twig sizes and on physiological processes, including those relating to seasonal changes in fire resistance, would be especially useful when planning use of fire. Fire needs to be considered at the regeneration stage with regard to reduction of slash, to preparing a seedbed, to controlling unwanted vegetation, and to promoting vigor in desired species. Fire should be evaluated for underburning to control certain vegetation. Slash burning for fire hazard reduction and/or preparation for planting should be studied.

Land managers are specifically asking for information enabling them better to predict fire effects on flora using fire behavior and/or fire danger rating variables. Managers with wilderness responsibilities particularly need this information.

Particularly in these pine types, studies are needed to interpret fire-caused vegetation changes in terms of wildlife food and cover needs.

DECIDUOUS FORESTS
EASTERN DECIDUOUS FORESTS

General Description

Eastern deciduous forests are located east of the Great Plains, primarily on four major physiographic divisions (fig. 11): (1) Interior Plains, (2) Interior Highlands, (3) Appalachian Highlands, and (4) Laurentian Upland. The climatic range is broad, being humid microthermal in the north and humid mesothermal in the south. Annual precipitation ranges from about 30 inches in the northwest to 60 inches or more in the southern Appalachians. The range of site conditions is great. There are about 50 major broad-leaved tree species and many times that number of minor tree, shrub, and herbaceous species found within the eastern deciduous forests. Küchler (1966) cover types are shown in table 9.

Eastern deciduous forests, including the effects of fire on them, are described by Braun (1950). Fire effects on these forests are also reviewed by Little (1974) and by Komarek (1974). Hare (1961) reviewed knowledge of heat effects on living plants.

Autecology

Many trees, shrubs, and herbaceous plants of the eastern deciduous forest are fire-adapted in that they may be topkilled by fire but will produce a new plant vegetatively by sprouts and/or suckers. Knowledge is far from adequate as to how sprouting ability is affected by tree size and age, by repeated fires (or cutting), by fire intensity, and by season of burn. Estimates of the proportion of vigorous sprouts produced following cutting can be made using species, diameter, and age for some oak species of the Missouri Ozarks (Johnson 1977). Sprouting of hardwood as related to species, degree of timber cutting, and age was reported for a study of southern Wisconsin hardwood stands (Rogers 1959).

Figure 11

Eastern Deciduous Forests

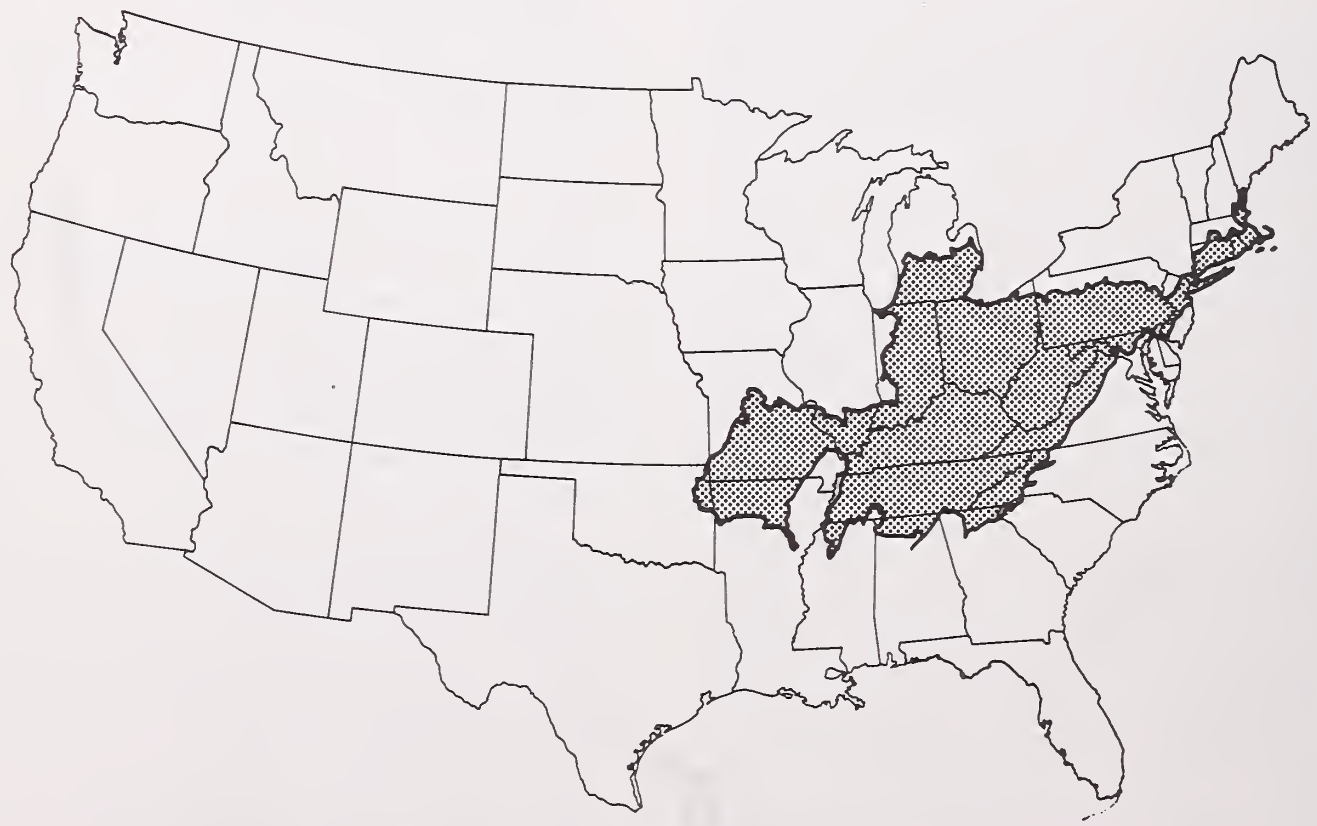


Table 9.—*Potential natural vegetation types (after Küchler 1966) and major tree species occurring in the Eastern United States*

Küchler type	Major tree species
Northern hardwoods—Type 97	Sugar maple *(Acer saccharum)* Yellow birch *(Betula alleghaniensis)* Beech *(Fagus grandifolia)* Hemlock *(Tsuga canadensis)*
Northern hardwoods—Type 97 (seral stages)	Aspen *(Populus tremuloides, P. grandidentata)* Paper birch *(Betula papyrifera)*
Maple-basswood forest—Type 90	Sugar maple *(Acer saccharum)* Basswood *(Tilia americana)*
Beech-maple forest—Type 93	Sugar maple *(Acer saccharum)* Beech *(Fagus grandifolia)*
Mixed mesophytic forest—Type 94	Sugar maple *(Acer saccharum)* Buckeye *(Aesculus octandra)* Beech *(Fagus grandifolia)* Tulip tree *(Liriodendron tulipifera)* White oak *(Quercus alba)* Northern red oak *(Quercus rubra)* Basswood *(Tilia americana)*
Elm-ash forest—Type 92	White ash *(Fraxinus americana)* American elm *(Ulmus americana)*
Oak-hickory forest—Type 91	Bitternut hickory *(Carya cordiformis)* Shagbark hickory *(Carya ovata)* White oak *(Quercus alba)* Red oak *(Quercus rubra)* Black oak *(Quercus velutina)*
Appalachian oak forest—Type 95	White oak *(Quercus alba)* Northern red oak *(Quercus rubra)*

Reduction in number and vigor of aspen root suckers through use of two or more spring burns in Minnesota was also reported (Buckman and Blankenship 1965).

A 2-year-old aspen *(Populus tremuloide),* stand established after clearcutting was burned and all trees were killed; subsequent suckers were more numerous but less vigorous (Perala 1974). Roth and Sleeth (1939) found that the ability of oak trees to sprout decreased with increased age. Kittredge (1934) reported sprouting capacity was high for basswood, but low for maple. Beech sprouts well from stumps of young trees, but sprouting ability decreases for trees 4 inches in diameter and larger (Fowells 1965). Beech also develops root suckers, but these will probably not develop into desirable trees (Fowells 1965). More of this type of research is needed.

Brown and Davis (1973) summarized the relative fire resistance of selected tree species of the Eastern United States. This summary provides information on basal bark thickness of mature trees, character of tree crown, character of stands, and rooting habit. Trees were placed in fire resistance groups with pitch pine *(Pinus rigida)* listed as resistant; yellow poplar *(Liriodendron tulipifera)* black oak,and eastern white pine *(Pinus strobus)* listed as moderately resistant; red oak, hickory *(Carya spp.),* and white oak listed as intermediately resistant; and sugar maple, yellow birch, and aspens listed as having low resistance. Pitch pine may be the most fire-adapted species in the Northeast as, in addition to having sprouting ability, it may produce viable seed by 4 years of age (Fowells 1965).

Synecology

The successional trend for the broad deciduous types, where site-climatic conditions are favorable and the species are present, would be toward increasing composition of the tolerant northern hardwoods (sugar maple, beech, basswood). In reporting on changes observed over a 30-year period in Connecticut mixed hardwoods, Olsen (1965) noted an expected increase in importance of both sugar maple and beech in the future, with decreasing importance of the present predominant oaks. The elm-ash type has lost most of its elms to disease, and without disturbance the successional trend would be expected to be an increase in the numbers of red and silver maples *(Acer rubrum, Acer saccharinum)* as well as white oak. In the northern part of the type, northern white cedar, where present, could very well become the predominant species. Oak-hickory is climax over much of its range because the site-climatic situation is unfavorable for northern hardwood species.

The composition and condition of the oak-hickory and Appalachian oak types at the time of settlement was significantly influenced by fire. The influence of fire on the northern hardwood types was probably not great. However, disturbances, such as fire were required to maintain the intolerant species within the northern hardwood forest. Presettlement and postsettlement fire history and vegetative responses have been summarized (Little 1974). Early fires in these "oak" types were believed to have been generally low intensity underburning at frequent intervals. This maintained open park-like stands and favored oaks over northern hardwood species. Swan (1970) reported that fewer northern hardwoods sprouted than did oaks after a fire. Also, northern hardwoods generally have thinner bark than oaks, making them more vulnerable to fire mortality or injury. Little (1974) summarized the effects of single and repeated fires following logging in northern hardwoods. Aspen-birch stands are likely to follow repeated postlogging fires.

Braun (1950) stated that a perusal of ecologic literature on the deciduous forest finds such literature largely confined to the peripheral areas. The exceptions to this are a number of papers dealing with vegetational features of the Great Smokey Mountains and other adjacent mountain areas. Braun (1950) listed important shrubs and herbs associated with various forest cover types. Plant communities of trees, shrubs, and herbs are described for the maple-basswood type (Daubenmire 1936, Kittredge 1934). Effects of annual and periodic (every 5 years) surface fires on characteristics of the over-story and regeneration in a Tennessee oak forest are reported by Thor and Nichols (1973), with characteristics of herbaceous and shrub vegetation being reported by De Selm et al. (1973). A study of an oak-hickory plant community (trees, shrubs, herbs) for a 10-year period following a fire was reported by Loomis (1977).

Many individual trees and stands of white, pitch, and Virginia pines *(Pinus virginiana)* found within the broad deciduous forest area may owe their existence to fires of the past, but soils and aspect are also variables that may favor pine.

Northern Hardwood Types

Northern hardwood types are: northern hardwoods (Küchler 1966: type 97), maple-basswood forests (Küchler 1966: type 90), and beech-maple forests (Küchler 1966: type 93). Fire is uncommon in northern hardwood forests. There are few reasons for considering use of fire during the life of a stand. These trees are very subject to basal wounding, which provides entry for decay. A study of decay in living northern hardwood trees in New Hampshire concluded, however, that fire wounds are not common in northern hardwood forests and that branch stubs are the main point for entry of decay agents (Shigo and Larson 1969). Burning under the northern hardwood forest has been reported in Canadian studies where the objective was conversion of low-grade, predominantly sugar maple stands to spruce, white pine, and yellow birch (Burton and Sloane 1958, Holowacz 1960, and Sykes 1964). Burning might also be considered to control undesirable understory vegetation to improve wildlife habitat. Graber and Thompson (1978) reported on the forest floor viable seed population found under northern hardwood stands that ranged in age from 5 to over 200 years. Cushwa, Martin, and Miller (1967) concluded that the effects of fire (heat and moisture) would increase germination of some species of seed.

Seral Stage of Northern Hardwoods (Küchler 1966: Type 97)

This type is more fire prone than the other northern hardwood types because more small shrubs and herbaceous plants are present under the less dense aspen-birch canopy.

Replacement of northern hardwoods by aspen and birch is primarily due to repeated fires. Generally these stands will return to northern hardwoods after the stand of aspen and birch has been cut. For various reasons it is often desirable to keep stands in aspen-birch, and fire is helpful in this respect. Prescribed fire is recommended the first dormant season following cutting of an aspen stand where unwanted living trees remain and aspen regeneration is desired (Perala 1974). To stimulate aspen suckering, most effectively, a ''moderate'' fire is recommended—one that will kill the vegetative cover and eliminate litter and part of the duff (Horton and Hopkins 1965).

Mixed Mesophytic Forest (Küchler 1966: Type 94)

Comments for northern hardwood types are also applicable to the mixed mesophytic forest. This type is more fire-prone than northern hardwoods with increasing composition of oak and intolerant species permitting more small shrub and herbaceous plants to be present. Also, oak leaves do not decay as rapidly as leaves of sugar maple, so they remain a significant ground fuel longer.

Fire at time of regeneration, following cutting, could prepare the seedbed for the additional valuable intolerant species—yellow poplar, black cherry, and sweetgum *(Liquidambar styraciflua)*. Yellow-poplar seeds have been found to remain viable in the forest floor for up to 8 years (Sander and Clark 1971). Wendel (1977) reported that black cherry seed were viable in the forest floor for 3 years, with some germination after 5 years; sassafras *(Sassafras albidum)* seed were viable for 5 years, and some wild grape seeds were viable for at least 8 years.

Elm-Ash Forest (Küchler 1966: Type 92)

This type is moderately fire prone, more so than the relatively fire resistant northern hardwood types, but less so than the generally fire-prone oak hickory and Appalachian oak forests.

Following clearcutting in this type, fire may serve to prepare a seedbed while topkilling unwanted residual trees and shrubs. In addition, slash reduction could be accomplished. Uses of fire during the life of the stand should be considered and tested for such problems as insects, disease, or understory control.

Oak-Hickory Forest (Küchler 1966: Type 91)

This type is quite fireprone with the principal fuel being oak leaves. Most fires are of low to moderate intensity. Entire stands are seldom killed except for young ones. Fire mortality and injuries caused by fire eventually become obvious, but at first they may be difficult to predict. Early investigators used discolored bark as an indicator of cambium damage (Nelson et al. 1933). Methods have been developed that can predict soon after fires are over how many trees will die and how serious basal wounds will be for surviving trees (Loomis 1973). There methods are applicable for black oak, white oak, and some other species of the oak-hickory forest type. In studying decay in upland oak stands in Kentucky, Berry (1969) reported fire scars to be the most important means of entry for decay fungi. Methods have been developed to estimate dollar value and volume loss for future sawtimber trees based on wound dimensions for northern red, black, scarlet *(Quercus coccinea)*, white, and chestnut *(Quercus prinus)* oaks (Loomis 1974). Jensen (1969) suggested that a certain oxygen level may be required to maintain active fungi activity. Perhaps open fire wounds provide the necessary oxygen level.

Larsen (1953) described the invasion of an oak forest in southern Wisconsin by red maple. He further stated that red maple is found in the oak forests of southern Wisconsin at the stage prerequisite for transition to maple-basswood. Rogers (1959) mentioned the lack of a successful method for establishing oak regeneration in southern Wisconsin stands and suggested that use of the selective action of fire on tolerant species be investigated as a potential management tool.

Appalachian Oak Forest (Küchler 1966: Type 95)

The Appalachian oak forest is quite fire prone as is the oak-hickory forest. Fires in this type frequently leave basal wounds on surviving trees. An early study presented equations for the prediction of cull volume based on wound dimensions for oaks (Hepting 1941). Roth and

Sleeth (1939) reported that sprout stands that follow a severe burn had lower decay incidence than those following cutting without fire. Another study reported relations between fire injury and fungal infection (Stickel and Marco 1936). Jemison (1944) reported that even severe basal wounding of oak stems by fire does not reduce the diameter growth rate, but if crowns are appreciably damaged or reduced by fire, diameter growth rate will be less.

Fire may be used to reduce slash following clearcutting. It may also have value as low intensity underburns for control of insects, disease, and unwanted vegetation. Prescribed fire may control laurel and rhododendron thickets (Hooper 1969). Romancier (1971) described how to control rhododendron thickets by using a combination of fire and silvicides.

Fire Characteristics

Much of the eastern deciduous forest at the time of settlement had been burned by the Indians (Braun 1950, Day 1953, Little 1974). In general, fires were probably infrequent and of low intensity in the northern hardwood types, but frequent and of low intensity in the oak types.

Effects of Fire and Management Implications

Fire may bring about a number of changes in the environment—an increase in light at the soil surface, an increase in daily temperature range at the soil surface, earlier development of vegetation in the spring, and earlier desiccation of the upper soil (Daubenmire 1974).

A possible fire-related problem is the inability of some species to reproduce successfully under themselves because of an allelopathic situation. This could be related to the theory of alternation of species (Spurr and Barnes 1973).

Differential bark thickness and insulating qualities by tree species and tree size are significant to a tree's ability to survive fire. A literature survey of bark characteristics and fire resistance was made by Spalt and Reifsnyder (1962). Martin (1963) reported on thermal properties of bark.

Research Needs

Research needs for eastern deciduous forests are much the same as for northeastern coniferous forests. Information on the effects of fire on flora of the eastern deciduous forest is limited. A major initial research need is a thorough review of applicable knowledge and literature; and assembling of information into appropriate planning and operational guides, where none exist. This would also help in the identification of specific research needs.

To better facilitate multiple-use management, there is need for postfire response information for entire vegetative communities. Studies are needed regarding sprouting ability of species as related to age, size, and other variables. Further studies concerning reproductive strategies such as kind and amount of viable stored seed present in forest floor and possible effects of fire on this seed would be of value. Another need is investigation of the possible role of fire in the reduction or elimination of allelopathic situations. Further research is also needed on fire adaptation (or susceptibility) of these species and adaptive characteristics such as bark thickness, bud and twig size, and other features. Fire needs to be considered in the regeneration process with regard to its effectiveness in preparing a seedbed, in controlling unwanted vegetation, and in promoting vigor in desired species. Underburning for controlling certain vegetation should be evaluated. Slash burning for fire hazard reduction needs to be studied.

SOUTHERN BOTTOMLAND FORESTS

General Description

The southern bottomland forests, (Küchler 1966: Type 103) southern floodplain forest)—also termed the wetland forests or the oak-gum-cypress forests—are composed of some 70 species of hardwoods in a multitude of mixtures. These forests occur on about 33 million acres in the broad bottomlands of major rivers, in small streams that meander through the southern pine forests, and in swamps that occur in river bottoms and at headwaters of Coastal Plain streams (fig. 12). These complex forests can be divided into two broad forest types: Tupelo-cypress swamps and mixed bottomland hardwoods (Stubbs 1973, Johnson 1973).

Effects of Fire in the Bottomland Forest

Because the Atlantic Coastal Plain normally receives adequate rainfall in the spring and summer, fires occur infrequently in this type except during extremely droughty years. However, when extended droughts do occur, such as the ones of 1844, 1860, 1910, 1931, 1954, and 1955 in the Okefenokee Swamp of southeast Georgia and north Florida, wildfires of high intensity accompany them and cause severe damage and high mortality to the timber (Cypert 1961 and 1973).

In the Midsouth, spring and summer rainfall is often inadequate (Langdon and Trousdell 1978), and droughts are more common there than in the Atlantic Coastal Plain. A study in the Mississippi Delta indicates that the probability of fire increases sharply when 60-day precipitation drops below 8 inches (Fahnestock 1959). For these reasons, wildfires of low to moderate intensity have occurred rather frequently in the Delta area (Lentz 1931). Such wildfires often cause injury to the hardwood trees, providing a point of entry for decay fungi. Consequently, decay of bottomland hardwoods following wildfire has been studied more intensively in the Delta region than in the Atlantic Coastal Plain (Hepting 1935, Kaufert 1933,

Figure 12

Southern Bottomland Forests

Toole 1957, 1959 and 1965, Toole and McKnight 1955 and 1956, and Toole and Furnival 1957). The rate of spread of heart rot in bottomland hardwoods following wildfire injury is predictable and varies between 0.9 foot and 2.0 feet per decade depending on the species (Toole 1959). These deleterious effects of wildfire result in lower quality and value of logs, with serious management implications.

Although prescribed burning seems to have limited usefulness in the tupelo-cypress swamps of the southern bottomland forest (Langdon 1971, Johnson 1973), it may be useful in the mixed bottomland hardwoods to control understory vegetation; to reduce fire hazard especially in the Midsouth; and possibly to regenerate stands of preferred species. Research conducted in other vegetation types with several species that also occur in the mixed bottomland hardwood forest indicates opportunities for and possible effects of burning. For example, burning has been shown to increase oak reproduction in West Virginia (Little 1974, Carvell and Tryon 1961) and to reduce decay in oak sprouts originating from stumps (Roth and Hepting 1943). Burning has also been used to increase seedling catches of yellow-poplar in New Jersey, Maryland, and South Carolina (Little 1967; Shearin et al. 1972). Yellow-poplar is unique in that its seeds remain viable in the forest floor up to 8 years (Sanders and Clark 1971) and burning apparently breaks seed dormancy and triggers germination. Little prescribed burning research on fire effects has been done in the southern bottomland forest; exploratory studies of fire behavior and fire effects are needed.

WOODLANDS AND CHAPARRAL

PINYON-JUNIPER WOODLANDS

General Description

The pinyon-juniper woodlands (Küchler 1966: Type 2)cover about 75 million acres in western North America, the area within the Great Basin sagebrush, sagebrush-grass steppe, and the Trans-Pecos shrub savannah (fig. 13). This area lies below the oakbrush and ponderosa pine zones, but above the grassland areas. Most of the material in this section is adapted from a state-of-knowledge review of the role and use of fire in the pinyon-juniper communities written by Wright, Neuenschwander, and Britton (1979).

These woodlands extend from the east slope of the Sierra Nevada Mountains, eastward through the Great Basin, throughout the Rocky Mountains of Colorado, and southward into Arizona, New Mexico, and northern Mexico. Juniper stands extend into eastern Oregon, southern Idaho, and Wyoming.

These communities may extend from 2,500 feet elevation to nearly 10,000 feet, but are more generally found from 4,500 to 7,500 feet. Annual precipitation ranges from 10 to 26 inches per year, but generally these woodlands exist in areas receiving 10 to 15 inches.

Dominant species of these woodlands are Utah juniper *(Juniperous osteosperma)*, one-seed juniper *(J. monosperma)*, Rocky Mountain juniper *(J. scopulorum)*, alligator juniper *(J. deppeana)*, two-leaf pinyon *(Pinus edulis)*, and singleleaf pinyon *(P. onophylla)*. Utah juniper is quite common and is distributed in northern Arizona, Utah, Nevada, and parts of California. Outside of the pinyon-juniper woodland proper western juniper *(Juniper occidentalis)* is abundant. Herbaceous species and grasses vary considerably throughout the pinyon-juniper zone. Shrubs that dominate the understory include big sagebrush *(Artemisia tridentata)*, black sagebrush *(A. nova)*, antelope bitterbrush *(Purshia tridentata)*, shrub live oak *(Quercus turbinella)*, cliffrose *(Cowania mexicanna)*, Gambel oak *(Quercus gambelii)*, serviceberry *(Amelanchier* spp.), and true mountain mahogany *(Cercocarpus montanus)*.

Synecology

Several workers have reported successional patterns following fire in pinyon-juniper (Arnold et al. 1964, Erdman 1970, Barney and Frischknecht 1974). Mature stands of juniper usually consist of considerable amounts of bare ground and litter that can inhibit grass production. A fire essentially establishes bare ground

Figure 13

Pinyon - Juniper Woodlands

that is then covered by annual and perennial grass species and increasingly larger amounts of young juniper plants. A climax pinyon-juniper forest may take as long as 300 years to develop. Pinyon-juniper communities are greatly affected by fire, drought, and competition. Droughts and competition from grass can slow the invasion and growth of junipers, but this can vary greatly between areas. Relatively frequent fires, about every 20 to 30 years, may have kept junipers restricted to shallow, rocky soils and rough topography. However, during recent decades, heavy livestock grazing has reduced grass competition as well as fuels for fires and has permitted pinyon and juniper to invade adjacent communities where previously they had been checked.

Fire Characteristics

Fire frequency and intensity can vary greatly in pinyon-juniper woodlands. Because of the arid regions in which this type occurs, severe fire weather is not uncommon. However, the existence of a continuous fuel bed is important in sustaining fire in much of this country, and mature pinyon-juniper stands are frequently too open, with up to 35 percent bare soil to sustain fire. Wind is also an important factor in carrying fire through open park-like stands. Therefore, depending upon conditions of the fuel bed and wind, fires may be similar to those found in grasslands or they may be large, intense, and spectacular as the pinyon and juniper itself is burned. Fires occurring at 20- to 30- year intervals may have kept much of this country originally in grassland and brush.

Management Implications

Fire is freguently used to increase production of grasses, and the production of grasses can increase dramatically following burning and seeding treatments. In open stands of pinyon-juniper, fire can be used effectively to kill pinyon and juniper trees less than 4 feet tall. However, larger trees are difficult to kill. Chaining or dozing may have to precede burning in order to kill the large trees. Prescribed burning or some combination of burning with other treatments is an effective procedure to reclaim closed pinyon-juniper stands (Aro 1971, Springfield 1976). Some combination of mechanical treatment and burning is usually considered an acceptable technique to avoid having to burn under severe conditions. Burning without other treatment must be done on hot days (95 to 100°F) with low relative humidity and 8- to 20-mile-per-hour winds; this is a situation considered too hazardous by most managers.

Mixtures of sagebrush and pinyon-juniper can be burned without prior treatment as other species provide fuel to carry the fire.

Reburning is needed to prevent reinvasion of pinyon and juniper. Reburns should be conducted at least every 20 to 30 years or when the tallest pinyon or juniper trees reach a height of 4 feet.

Research Needs

Research needs in the pinyon-juniper type fall into two general categories: (1) Prescription techniques to burn pinyon-juniper communities and (2) information on the response of understory species to fire.

Generally speaking, guides exist for writing prescriptions to burn pinyon-juniper communities. However, because of the potential for the escape of fires, managers are not always comfortable with them. We need to know where pinyon-juniper stands can and cannot be burned and under what conditions. We have reasonably good information for burning mixed stands of pinyon-juniper and sagebrush, but more information is needed on the techniques of pulling off the burn. In open pinyon-juniper grasslands, information is needed on the amount of fire fuel needed to carry a fire.

Probably the biggest challenge from a research standpoint is to complete our data base on the response of understory species to fire. Information is needed on successional development in these stands following fires of known characteristics.

WESTERN OAK WOODLANDS

General Description

Oak woodlands (Küchler 1966: Types 22, 24-28) are located between grasslands and the montane forests (fig. 14). The dry lower edge is defined by the absence of oak trees. Dense forest replaces the woodland at the moist upper edge. The upper border is often obscured by a chaparral zone between the woodland and the forest. Dominant trees in the California foothills are blue oak *(Quercus douglasii)*, digger pine *(Pinus sabiniana)*, valley oak *(Quercus lobata)*, and interior live oak *(Quercus wislizeni)*. In southern California, Engelmann oak *(Quercus engelmannii)* and coast live oak *(Quercus agrifolia)* are more important. In Oregon and northern California, oak woodlands consist primarily of Oregon white oak *(Quercus garryana)*; Gambel oak *(Quercus gambelii)* dominates in western Colorado and Utah, while Emory oak *(Quercus emoryi)*, Mexican blue oak *(Quercus oblongifolia)*, and alligator juniper *(Juniperus deppeana)* are most common in southeastern Arizona. Understories in the woodlands are primarily annual forbs and grasses. Near the upper boundaries, brush species become more dominant in the understory.

Autecology

Deep rooting systems allow the oaks to survive in the woodland areas where moisture stress can be extreme. Mature oaks have relatively fire-resistant bark layers that enable them to survive low-intensity grass fires.

Synecology

The lower boundary of the woodland type is defined by moisture availability. The forest is a savannah type with low densities of trees. As moisture increases, other species are able to compete with the oaks, and a woody understory is more prevalent. On mesic slopes, the woodland type would probably approach the mixed hardwood forest. Without fire, a highly flammable understory of pines and live oaks will develop. The mature deciduous oaks might not be able to survive the next fire, and the live oaks would sprout and replace them.

Fire Characteristics

Fires in the woodland type are generally of low intensity although fast moving. In areas with highly flammable grasses, fires can burn frequently through the forest. More often, however, intervals between fires are long. As fuels increase near the upper boundary of the type, intensities become greater.

Fire Effects

The low-intensity fires that usually occur in the oak woodlands have little direct effect in physical properties. Water yields from these woodlands are increased as woody vegetations becomes less dense. The shifts between grasslands on one side and forests on the other are manifestations of the most pervasive ecological effect of fire. Since these oaks are primarily nonsprouters, the interval between fires is very important.

Herbaceous rare species could be adversely affected by too frequent burning in the woodlands.

Management Implications and Research Needs

Much of the land occupied by oak woodlands is used as rangeland. Woody species consume water that would otherwise be available for forage. Fire can be used to convert woodlands to grasslands. For all oak woodlands, details on floristic composition, stand structure, successional trends, and fire dynamics are needed.

Figure 14

Western Oak Woodlands

SCLEROPHYLLOUS HARDWOODS

General Description

Two recent reviews of sclerophyllous hardwood vegetation (Küchler 1966: Types 29-31) and fire's role in this type exist (Hanes 1977, Biswell 1974). Much of the literature on the effects of fire in Mediterranean ecosystems is included in Mooney and Conrad (1977). This section draws largely on these sources.

Sclerophyllous hardwoods occur throughout the Southwestern United States, primarily in California (fig. 15). The term chaparral is used to describe the brushy sclerophyllous species. Dominant chaparral genera include *Adenostoma, Arctostaphylos, Ceanothus,* and *Quercus*. Evergreen woodlands are dominated

Figure 15

Sclerophyllous Hardwoods

by tree-forms of the genera *Arbutus, Lithocarpus, Quercus,* and *Umbellularia.*

The plants are characterized by extensive root systems; dense rigid branching; and small leaves, which are heavily cutinized and evergreen. California chaparral is differentiated from Rocky Mountain chaparral by seasonal activity patterns. In California, the Mediterranean climate predominates with mild, moist winters and hot, dry summers; winter is the active growing season. In the Rockies, the chaparral is summer active and winter deciduous.

Autecology

The sclerophyllous hardwoods have several adaptations, which allow them to reproduce in a harsh environment subject to frequent fire. Some species subject to short intervals between fires gain a competitive advantage by producing seeds early in the season, thus allowing them to take advantage of the limited amount of moisture in the soil. Sprouting after fire is the most common reproductive strategy employed by chaparral and evergreen woodland species.

Species of each of the common genera are vigorous sprouters. Most of the species, including both sprouters and nonsprouters, have resistant seeds that retain their viability for decades and in some cases require fire before they can germinate.

Synecology

The ecological status of sclerophyllous hardwoods varies depending on location. In some mixed evergreen forests, succession without fire tends to favor the coniferous species. The stands gradually succeed to conifers as the hardwoods senesce and are outgrown. Hot fires swing the balance toward the hardwoods since the conifers do not sprout. After a moderate burn, both types regenerate since adequate conifer seeds are usually present.

Chaparral stands in the coastal mountains of southern California are considered to have reached a steady state. These stands have been predominatly chaparral as far back as records go, are largely fire induced, and grow on shallow and infertile soils with little waterholding capacity. Fire serves as the major cause of succession in this chaparral by creating the conditions necessary for establishment. The density of vegetation, its flammability, and the extreme dryness of the summer climate make chaparral susceptible to fire. In fact, fire maintains the type and ensures the prepetuation of most of its species. Different intervals between fires can shift species composition, but in most cases the vegetation is self-repeating.

A band of chaparral vegetation exists in the foothills of the Sierra Nevada Mountains between the forested areas at higher elevations and the grasslands below. Frequent fires maintained the lower portion of this band as grasslands since grasses were favored over shrubs. The absence of fires allows shrubs to invade and increase in density, forming a chaparral vegetation cover. At higher elevations, chaparral often occurs on large acreages as a stage of secondary succession in coniferous forests. Following disturbances such as fire, seedlings from both sprouting and nonsprouting shrubs may appear. A mixture of chaparral and forest results, with the shrubs occupying spaces vacated by trees. In forest dominated areas, frequent low-intensity fires favor the fire resistant tree species over the nonsprouting shrubs.

Fire Characteristics

Intense fires can occur from 15 to 30 years or more apart in the evergreen hardwood type. These fires can reduce the forest to bushy thickets consisting of hardwood sprouts and chaparral species. Increased frequencies perpetuate this form. The more common longer interval allows the forest to grow and the fuels to accumulate. The consequent fire can be extremely intense.

Fires in mature chaparral stands are intense, often exceeding 30,000 BTU's per second/foot. Flame lengths can exceed 50 feet and rates of spread have been recorded at over 600 chains per hour. These intense, fast-moving fires can burn entire watersheds in minutes, leaving nothing but burnt stands.

Soon after the fire, however, sprouting species begin to regrow, and after the first rain, seedlings appear from the nonsprouters. Intervals between fires vary from 10 to 40 years, with an average of around 20 years.

Effects of Fire

Fires burning in chaparral can have considerable effects on soils. Soil erosion is usually accelerated following fire, depending on the erodability of the soil; steepness of slope; time, amount, and intensity of rainfall; plant cover; severity of fire; and length of time since the last burn. Dry creep erosion may be severe immediately after intense fires on slopes above the angle of repose.

Some chaparral soils develop water-repellent layers. When intense fires occur, hydrophobic compounds in the litter are polymerized and diffused downward where they condense on cooler soil particles. Sometimes the entire water-repellent layer is transferred from the surface to below the surface. Mudflows frequently occur when the soil above the water repellent layer becomes saturated and begins to shear.

Allelopathic substances are associated with some chaparral species. These toxins inhibit seed germination and growth of herbaceous species. Little new growth occurs until the toxins are destroyed by fire.

Nutrients contained in chaparral plants are rapidly recycled when subjected to high temperature during fire. Some nutrients, such as calcium, magnesium, and sodium are released and deposited on the soil surface. Others, such as nitrogen and potassium, are volatilized.

The ecological effects of fire in chaparral are as diverse as the vegetation itself and the fires that burn through it. Most of these effects have been discussed in the sections on autecology and synecology. The long-term effects relate to the evolution of these species in the presence of various fire regimes. Through the evolutionary process, plants subjected to periodic fires over thousands of years have developed highly flammable characteristics. Chaparral species have high surface-area to volume ratios, high fuel bed porosity, and a high oil content in the leaves. They also grow rapidly after fire and in about 15 years begin to develop dead branches. The stands mature by 25 years and begin to senesce soon thereafter. These features create a system-dependent feedback loop where the chaparral depends on periodic fires every 15 to 20 years for optimum health and stability yet must produce an adaquate fuel bed to support the fire it needs.

Since the sclerophyllous hardwoods evolved with fire, those plants within the type that have become threatened or endangered are those that have suffered from the removal of fire from the type. For instance, the Smithsonian Institution report states that in California there are 14 threatened and 11 endangered species of *Arctostaphylos* and 5 threatened and 4 endangered species of *Ceanothus*. Many more fire dependent plants, especially forbs, require fire for their perpetuation. Few species that were part of the original vegetation are adversely affected by fire.

Management Implications and Research Needs

Fire in chaparral is both natural and inevitable. The closer management practices follow the natural process, the more successful they will be. Fire suppression in such a vegetation is increasingly expensive and the chances of complete control decreasingly probable as the stands age. Burning under prescribed conditions will be necessary to return the thousands of acres that have been overprotected in the past to a reasonably safe condition. Intervals between fires must be carefully controlled if specific species compositions are desired. Fires that are frequent will eliminate nonsprouters, while long intervals between fires might eliminate short-lived species.

Since young chaparral stands seldom burn, the objective of prescribed burning should be to break up large old stands into a mosaic of age classes so that a wildfire, once ignited, would not spead uniformly over large areas.

The characteristic vegetative patterns of the sclerophyllous hardwoods and their successional relationships are not well understood. Additional work is necessary to determine the role fire plays in developing this complex mosaic of vegetation.

Information is needed on the ability of fires to spread in chaparral stands of various age classes. Also historical geographical age class distributions need to be known, as well as the extent of historical fires. Research on the environmental conditions for prescribed burning must also be done.

NONFOREST AREAS
DESERT

General Description

The desert areas of the Southwest include the Mojave Desert in California, the Sonora Desert in California and Arizona, and the Chihauhuan Desert in west Texas and New Mexico (fig. 16).

Creosote bush *(Larrea tridentata)* and white bursage *(Franseria dumosa)* characterize the Mojave Desert. Fire tolerant species include Joshua tree *(Yucca brevifolia)* and California fan palm *(Washingtonia filifera)*. Woody species and cacti are common in the Sonoran Desert, while the Chihuahuan Desert is typified by creosote bush and tarbush *(Flourensia cernua)*.

Autecology

As would be expected, moisture plays the dominant role in the autecology of the desert species. Fire, where it does occur, is important in the balance between grasses and woody plants. Joshua trees are capable of producing vigorous stump and root sprouts after fire. Dense stands are attributed to a combination of adequate moistue and high fire frequency. The trunks and crown of California fan palms are reduced in diameter by fires, thereby reducing their transpiration rates. This allows the trees to come into balance with their limited water supplies. Herbaceous annuals reproduce by seeds that are able to survive until adequate moisture conditions occur.

Synecology

Fires are a factor in the hot desert only in those infrequent years when winter rains are exceptionally heavy and abnormally heavy stands of herbaceous annuals are produced. If a fire does occur during these years, it usually burns near the desert boundary. In those areas, which might be more correctly classified as grassland, the fires tend to keep the woody plants in check. Years of overgrazing have killed the grasses in many areas. Without this fuel, fires have not been able to keep the woody plants from invading the desert.

Figure 16

Desert

Fire Characteristics

Fires are rare in the desert. They do not spread over wide areas and only occur infrequently. Since annual plants constitute the primary fuel for these fires, they are of low intensity. The noncontiguous nature of the fuels prevents wide area fire spread.

Effects of Fire

In mountainous desert areas, fires can lead to water erosion and considerable soil loss. The sparse grasses are slow to regenerate, leaving the soil exposed, especially during the first year after a burn.

The most pervasive ecological effect of fire in the desert has been its control of woody plants in the ecotone between desert and grassland. These grasslands have been invaded by mesquite *(Prosopis juliflora)* and creosote bush in the absence of fire. Although these plants are able to sprout, they have thin barks and are very susceptible to fire damage and killing. Frequent fires burning through desert grasslands eliminate these woody plants.

Not much information exists on the effect of fires on threatened and endangered desert species. Since fire has not been a prevalent factor in deserts, it is assumed that those species that are rare did not develop fire-related adaptations. Rare species in the desert-grassland ecotone, however, would be favored by the return of a natural fire regime.

Management Implications and Research Needs

It appears that the primary interest for managers with respect to fire in deserts is in the grassland ecotone. Here, the absence of fire from overgrazed or overprotected areas has reduced the value of the range for forage.

Few fires have been studied in desert areas. Initial studies have been undertaken on the invasion of woody plants into grasslands and the use of fire to reverse this trend. Additional work needs to be done.

PRAIRIE GRASSLANDS

General Description

The North American grasslands (Great Plains) lie between the Rocky Mountains and the western boundary of the oak-hickory forest and extend from the south-central Texas to the aspen parklands in central Alberta and Saskatchewan (fig. 17). The area is commonly divided from west to east into shortgrass, mixed, and tallgrass prairies and grassland-forest communities (Launchbaugh 1972). Wright and Bailey (1979) divided the area into three geographic units: (1) southern Great Plains, (2) central Great Plains, and (3) northern Great Plains. Their work and Vogl's (1974) are the source for much of this section. In fact, anyone interested in this subject should refer to Ahlgren and Ahlgren 1960, Daubenmire 1968, Garren 1943, Vogl 1974 and 1979, and Wright and Bailey 1979.

Mixed Prairie

The mixed prairie (rolling plains) is found in west-central Texas and eastern Oklahoma. Elevation is from about 3,000 feet in the west to 900 feet in the east. Precipitation varies from 20 to 28 inches per year. Honey mesquite and Ashe juniper *(Juniperus ashei)* dominate the overstory in Texas. Dominant grasses include side oats grama, tobosa grass, buffalo grass, little bluestem *(Schizachyrium scoparium)*, and Texas wintergrass *(Stipa leucotrica)*. Annual forbs can be present following wet winters.

The tall grass prairie is found in central Texas and Oklahoma in the east. Tall grasses are mixed with post oak *(Quercus stellata)* and blackjack oak *(Q. marilandica)*. Precipitation is from 27 to 45 inches per year, with elevation from 500 to 1,000 feet. Dominant grasses are little bluestem, big bluestem *(Andropogon gerardi)*,

Figure 17

Prairie Grasslands

Indiangrass *(Sorghastrum nutas)*, switchgrass *(Panicum virgatum)*, and eastern grama grass *(Tripsacum dactyloides)*.

Central Great Plains

The central Great Plains lie between the foothills of the Rockies in Colorado and Wyoming and the grassland-forest of Missouri, Iowa, and Illinois, and comprise the Great Plains of Kansas and Nebraska. Shortgrass prairie exists in Colorado, Wyoming, and western Kansas and Nebraska. Precipitation is from 11 to 18 inches per year, and elevation is from 5,000 feet in the west to 3,000 feet in the east. Dominant grasses on dry sites include blue grama, prairie sandreed *(Calamovilfa longifolia)*, and needle-and-thread *(Stipa comata)*. On loamy soils, buffalograss, blue grama, western wheatgrass, and scarlet globemallow are common.

Mixed prairie is found in western Nebraska and Kansas. Elevation varies from 1,300 feet in southern Kansas to nearly 5,000 feet in northwestern Nebraska. Precipitation is from 18 to 28 inches per year. Dominant grasses include blue grama, little bluestem, sand dropseed, tall dropseed *(Sporabolus asper)*, western wheatgrass, buffalograss, side oats grama, purple three arm *(Arista pupurea)*, needle-and-thread, and junegrass *(Koeleria cristata)*.

Tallgrass prairie is found in eastern Nebraska, Iowa, and eastern Kansas. Annual precipitation is from 23 to 40 inches, with some tallgrass prairie in the Sand Hills of Nebraska receiving only 18 inches. Topography is gently rolling at elevations of 500 to 2,000 feet. Tallgrass prairies include little bluestem, big bluestem, switchgrass, Indiangrass, and prairie dropseed *(Sporobolus heterolepis)*. Dominant shrubs include snowberry *(Symphoricarpos occidentalis)*, ceanothus *(Ceanothus ovatus)*, lead plant, willow gooseberry, and prairie rose *(Rosa arkansas)*. A wide variety of forbs has been described. As we move into the tallgrass prairie, eastern tree species begin to occur including American elm *(Ulmus americana)*, hackberry *(Celtis occidentalis)*, eastern red cedar *(Juniperus virginiana)*, bur oak *(Quercus macrocarpa)*, chinkapin oak *(Q. muehlenbergii)*, eastern redbud *(Cercis canadensis)*, bitternut hickory *(Carya cordiformis)*, and roughlead dogwood *(Cornus drummondii)*.

Northern Great Plains

The northern Great Plains are found in eastern Montana, eastern Wyoming, North Dakota, South Dakota, and western Minnesota. Only mixed prairie and tallgrass prairie are found on the northern Great Plains.

The mixed prairie includes eastern Montana, eastern Wyoming and most of the Dakotas. Precipitation is from 10 to 20 inches per year, and elevations are from 1,300 to 4,100 feet. Grasses are mainly blue grama, needle-and-thread, green needlegrass, western wheatgrass, bearded wheatgrass *(Agropyron dasystachyum)*, threadleaf sedge *(Carex filifolia)*, Sandberg's bluegrass *(Poa scunda)*, plains muhly *(Mulenbergia cuspidata)*, and junegrass. Rough fescue is found on Montana foothills. Forbs are not abundant and shrubs are predominantly fringed sage *(Artemisia frigida)*, herbaceous sage Nuttall's saltbush, winterfat *(Eurotia lanata)*, and plains prickly pear. Dakota stands have more little bluestem, green needlegrass, and western porcupinegrass *(Stipa spartea)*. In mixed prairies there are more abundant forbs.

The tallgrass prairie is found in eastern North and South Dakota and in western Minnesota. Precipitation is from 19 to 30 inches and elevations are of 800 to 1,800 feet. Grasses and forbs are similar to tallgrass prairie in the central Great Plains. In Minnesota, the tallgrass prairie begins to mix with the forests of the Lake States.

Prairie Ecology and Fire

Classical concepts of plant succession as proposed by Clements (1916) and Weaver and Clements (1938) do not handily apply to the prairie situation. These concepts viewed plant succession as linear, with one set of species replacing another unitl a "climax" community existed. The climax community was adapted to the environmental conditions for that particular site. Prairie or grassland is in reality much more complex than this. Prairie species respond to a complex set of factors including grazing, droughts, and burning, vegetative reproduction habits, allelopathic relationships, seed production, moisture adaptive traits, and productivity of particular species. Vogl (1974) suggested classifying grassland species as increasers, decreasers, neutrals, invaders, and retreaters.

There has been considerable discussion of the role of fire and climate as primary factors in the establishment of prairie communities. Stewart (1951 and 1953) and Sauer (1944) proposed that treeless grasslands are the result of repeated fires. However, Wedel (1957) and Hastings and Turner (1966) made a strong case for climate as being the primary factor.

Wright et al. (1978) felt that climate is a dominant factor that characterizes North American grasslands. We know that drought, fire, insects, rodents, and autecological factors all combine to characterize the prairie grassland. For example, shrubs and trees have always, to some extent, existed on the grassland and are most abundant on the southern mixed prairie, eastern tallgrass prairie, and rocky breaks or heavily grazed areas where fires are least frequent.

Droughts can control the abundance of shrubs where grass is healthy, but succession from grasslands to shrubs and trees can occur on a 100-year cycle if climate is a major factor. With fire as a factor, there is no doubt that shrub or tree growth is restricted. Results depend upon not only the autecology of species involved but also burning frequency, fire intensities, climate, soils, biotic factors, and the like. We need to know the kind of relationships described by Wright et al. (1978) to understand the effects of fire on specific communities.

Some woody plants can tolerate fire; but, in areas subjected to high fire frequencies, odds are that grass species will be favored. Fire usually injures or kills most living woody plant tops while grassland species have abilities to respond rapidly following the fire.

In forest communities, fire tends to decrease species composition and stand structure, while the response in grasslands is more varied. Fires can increase the number of species, particularly annuals. Sometimes fires increase forb production and sometimes not (Daubenmire 1968). Fires may even create monotypes in grasslands by stimulating reproduction of dominants and eliminating other species. In other cases, fires may permit invasion by annuals, short-lived perennials, weeds, or agressive exotics. The important point to be made is that to interpret the ecology of grasslands, one must understand the autecology and synecology of the species involved; the frequency, timing, and intensity of the fire; and the environmental factors for particular situations.

Daubenmire (1968) pointed out the complexities. Vogl (1974) did likewise, but was reluctant to generalize, and Wright et al. (1978) reported specifics, however, in fact in much too great detail to summarize here. We will, however, attempt some generalizations.

Native warm-season perennials are usually favored by burning. Seed production, germination, and seedling establishment of both annuals and perennials are commonly encouraged by fire. Fire often triggers and encourages germination of seeds. For some forbs, fire is required to break dormancy of seed. In the case of many annual grasses and forbs, bare mineral soil and full sunlight are required for seedling establishment.

Timing of burning is extremely important. If an area is burned after annuals have begun growth, fire can be detrimental. Often other factors trigger growth, and if the fire occurs following growth, it can set back or eliminate the species, particularly when burning occurs before seeds are set.

Most perennial species are capable of vegetative reproduction. This provides these species with the ability to survive fire. A more complicated, but little understood situation involves allelopathic relationships. Fire frequently regulates inhibitory effects of plants.

The situation regarding the effects of fire in prairie grasslands is difficult to summarize because of complex plant successions, the role of climate on these plant communities, and the lack of definitive studies with known fire characteristics. There is great need for state-of-knowledge reviews, such as the one by Wright et al. (1978), and subsequent research to clarify these complexities.

Fire Characteristics

Lightning storms and people's carelessness are major causes of fire in grasslands today. However, fires have always been common on the prairies during drought years. Large fires often occur during drought years that follow 2 or 3 years of excellent plant growth. Once a fire is started, it can travel for many miles if winds are high, relative humidity is low, and air temperatures are high (and if fuel beds are contimous). Fires on the prairie were often measured in terms of millions of acres or square miles. However, today, larger fires are often curtailed because the prairies are being broken up with cultivated land.

Because trees are not present in most of the prairie country, we do not have good historical records on fire frequency. Several authors (Weaver 1951, Wagener 1961, Arno 1976, Chapman 1926, and Chapman 1944) indicate that the fire frequency in pine forests varies from 2 to 25 years. Wright et al. (1978) believed that the natural fire frequency in prairie grasslands is probably on the order of 5 to 10 years.

SAGEBRUSH-GRASSLANDS

General Description

Sagebrush-grass communities are common and widely distributed in the Western States (fig. 18). Because they are found in mixtures with other vegetation zones, it is difficult to estimate the size of their coverage. They probably cover about 100 million acres and are found between 2,000 and 7,000 feet elevation. One of the largest contiguous areas, the Great Basin country, is found in eastern Oregon, northern Utah, and northern Nevada. Precipitation is usually low—between 8 and 20 inches per year. Commonly, these communities are found at elevations below the pinyon-juniper in the Great Basin, but may be just below ponderosa pine, Douglas-fir, oak-brush, or mountain mahogany. A state-of-knowledge review by Wright et al. (1978) was used for preparing this section.

Fire Characteristics

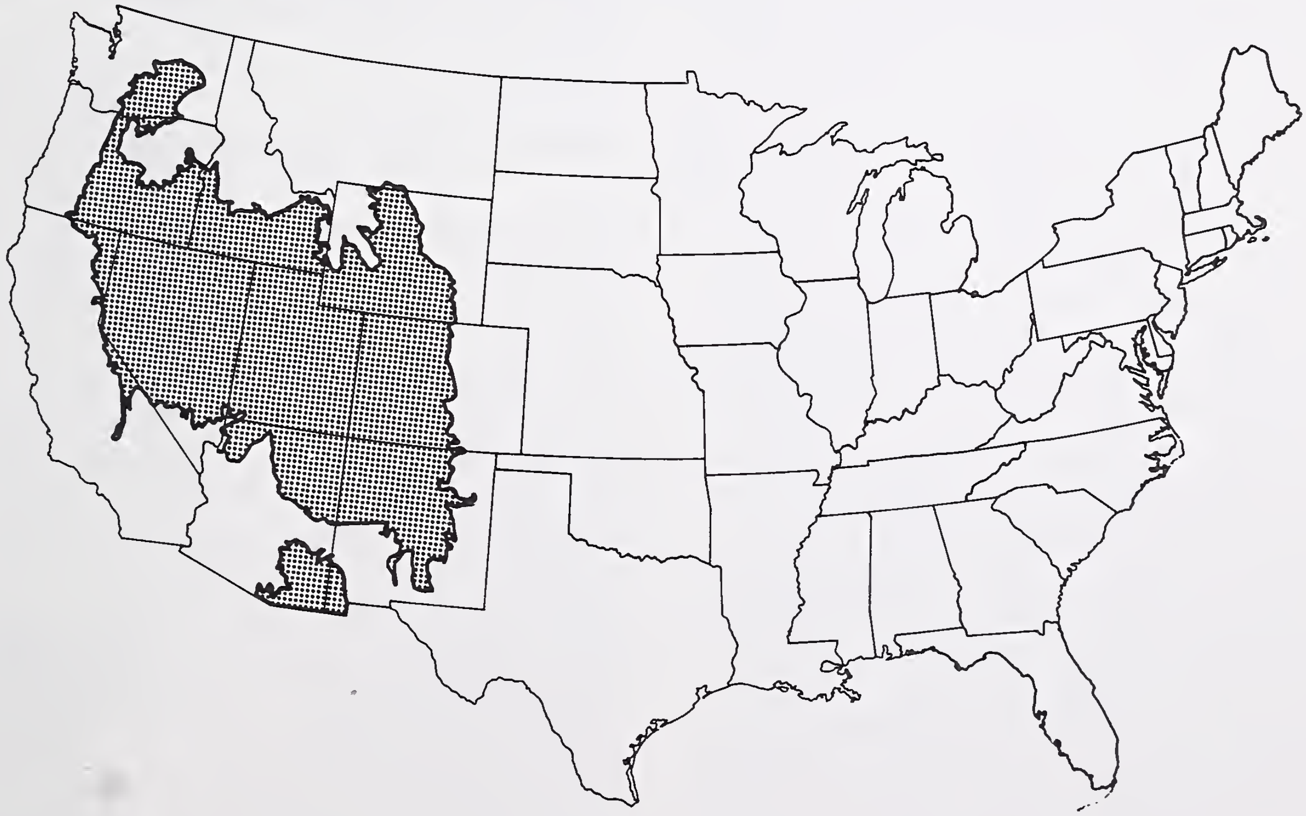
Natural fire frequency in these communities is probably about every 25 to 50 years. Intensity varies with the cover of sagebrush. Fires can be intense, with high rates of spread. Fuel loadings of 600 to 700 pounds per acre are needed to burn these communities readily.

Effects of Fire

Big sagebrush *(Artemisia tridentata)* is the dominant species on these areas. Numerous

Figure 18

Sagebrush - Grasslands



other species of sage are commonly found together with antelope bitterbrush *(Purshia tridentata)*, horsebrush *(Tetradymia* spp.), rabbitbrush *(Chrysothamnus* spp.), and brown snake weed *(Xanthocephalum sarothrae)*. Dominant grasses are bluebunch wheatgrass *(Agrophyron spicatum)*, Idaho fescue *(Festuca idahoensis)*, needle-and-thread *(Stipa comata)*, Thurber needlegrass *(Stipa thurberiana)*, and Indian ricegrass *(Oryzopsis hymenoides)*. Forbs vary considerably but are often abundant.

With this variety of vegetation, fire effects can vary also. The season of the burning can greatly affect results. For example, the effect of fire on grasses depends upon both their growth form and season of burning (Wright et al. 1978). Bunchgrasses can be severely damaged by fire, especially in June or July (Blaisdell 1953, Wright 1971). The dense clumps will burn for several hours after the fire front passes and the clumps subsequently die, regardless of the intensity of the fire front. Current fire spread models would not suffice for predicting this type of fire effect since they do not consider persistance of burning. Idaho fescue and needle-and-thread are species greatly affected. Studies have been made relating production to time since burn for many species.

Repeated burning or spring burning can deplete perennials and allow annuals such as cheatgrass to dominate. Techniques exist for reseeding areas that are in early stages of succession.

THE FOREST SOIL ENVIRONMENT

QUANTITY OF WOOD IN FOREST SOILS

The persistence of wood in forest soils has been recognized only recently. Estimates of the quantity of decayed wood in soils vary but in all cases are substantial. Day and Duffy (1963) estimated that decaying wood made up 16.5 percent of the surface area of one stand in the Rocky Mountains of Canada. McFee and Stone (1966) measured the volume of decayed wood on several forest plots in the Adirondack region of New York State. They reported from 14 to 30 percent of the surface area of these stands was made up of decayed wood. Measurements from western Montana showed 15 percent of the top 15 inches of soil consisted of brown, cubical decayed wood (Harvey et al. 1976).

FUNCTION OF WOOD IN FOREST SOILS

The processes and organisms involved in the decay of wood are essential to soil development. They have a direct influence on carbon and mineral cycling. Preliminary measurements indicate that decayed soil wood has a higher cation exchange capacity than any other component in several of the rocky soils of western Montana. Wood represents a potentially important site for retention of plant nutrients.

Nonsymbiotic nitrogen fixers are dependent on soil organic matter as a substrate to support their activities. Data from western Montana show that humus and decayed wood are the principal sites for this activity, particularly on dry sites (Larsen et al. 1978, Harvey et al. 1978b, Jurgensen et al. 1977). Nitrogen-fixing activities have also been reported in decaying wood in the Southeastern (Carnaby and Waide 1973), the Northeastern (Bormann et al. 1977), and Northwestern United States (Aho et al. 1974).

Nonsymbiotic nitrogen fixation is critical to forest ecosystems in the northern Rocky Mountains. In the Rocky Mountain region, symbiotic nitrogen-fixing plants are frequently less common then in many other regions. Their presence is restricted to early stand development or limited by habitat requirements.

In mature forest ecosystems of the northern Rocky Mountains, over 90 percent of the active ectomycorrhizal roots of a forest stand are supported by soil organic matter (Harvey et al. 1976). During dry periods or on dry sites, most of this activity is supported by decayed wood (Harvey et al. 1978a and 1978b). Ectomycorrhizal activity in decayed soil wood has also been observed in western Canada (McMinn 1963) and the Northwestern (Zak 1971, Trappe 1965) and Northeastern United States (McFee and Stone 1966).

Wood in forest soils is, therefore, responsible for major contributions to soil quality and stand growth in a broad geographical area.

DECAY-FIRE INTERACTION

The incorporation of wood into forest soils involves a choice or a combination of biological (decay) and physical (fire) forces. Decay is efficient in warm-wet ecosystems where fire occurs infrequently. Conversely, the decay process is slow in cold or dry ecosystems where fire occurs more frequently.

Decayed wood consists primarily of complex lignin molecules highly resistant to further biological breakdown. Therefore, highly decayed soil wood should accumulate even on warm-moist sites despite rapidity of decay. On dry or cold sites, decay is impaired. These sites should accumulate relatively undecayed woody debris until the occurrence of a wildfire. Fuel accumulation leads to hot wildfires that remove even large fuels. This will likely deplete the soil wood leading only to accumulations of soil charcoal. Sites with intermediate conditions of temperature and moisture should provide a more balanced relationship between these forces.

Preliminary field data indicate that these types of relationships do hold, at least for selected areas, in the northern Rocky Mountains.

MANAGEMENT OF WOOD IN FOREST SOILS

Demonstrations that soil organic reserves, particularly wood, play important roles in maintaining forest site quality emphasize the need to manage wood materials as a resource. Thus, the viewpoint that wood residue represents only waste or a liability as fuel must be reassessed. Forest users and managers must recognize the benefits—equivalent to long-term fertilization—that woody and other organic reserves contribute to forest ecosystems.

While our knowledge about nutrient quantities required for optimum site condition is limited, we do know enough to establish preliminary management guidelines.

Within the northern Rocky Mountains, the high productivity and rapid decay rates of warm-moist forests make them less sensitive to depletion than sites with low to moderate productivity. However, in specific instances, managing for certain types of old-growth forests may retain aspects of decayed wood conservation, even on productive sites (Franklin et al. 1979). Conversely, dry or cold site management should emphasize conservation of as much large woody material as possible, yet not create an unacceptable wildfire risk. Such woody materials should, where possible, be left in contact with the soil to create optimum conditions for decay.

In most geographical areas, where early access to mineral soil seedbeds is critical to reforestation, post-harvest slash treatments should be directed toward creating a mosaic of fuel dispersal. It will be advantageous to have both large woody residues and bare mineral surface scattered across the site so seeds can germinate rapidly and the seedlings have access, within a short distance, to the nutrients, moisture, and ectomycorrhizal activity provided by decaying wood and humus. Size of both slash piles and windrows for prescribed burning should be dictated by minimum standards that will achieve adequate small fuel reduction. Soil disturbance should be minimal and not create continuous expanses of mineral surface.

Management of wood on intermediate sites is less clear. Until more data are available, such sites should be treated as if they are at least moderately sensitive to reduction of soil wood.

An awareness by foresters of the importance of wood and other organic reserves to forest ecosystems and to the potential site degradation caused by their depletion should result in improved forest practices throughout a wide range of geographical areas.

MAJOR DISEASES AND FIRE

In summarizing the effects of fire on forest diseases, Parmeter (1977) commented, "Of the many possible fire/disease interactions, few have been demonstrated by 'hard' evidence, and even fewer have been studied sufficiently to permit estimates of ecological or economic impacts. . . . Effects may be direct and rapidly manifested or they may be indirect and years removed from the event. They may involve simple, readily discernible changes such as the creation of infection courts, or they may involve complex chains of interactions among hosts, insects, microorganisms, and changes in the physical and chemical environment."

Brown-Spot Needle Blight

Of the fire-related forest diseases, brown-spot needle blight *(Scirrhia acicola)* of longleaf pine *(Pinus palustris)* probably is the best known and has been the most thoroughly researched. Fungus attack of needles of seedlings leads to irregularities in stocking, uneven height structure of the forest, and a lengthening of the rotation. Because "grass"-stage longleaf is fire hardy, prescribed burning can be used as an effective sanitizing treatment. Successful burns depend on continuity of fuel to carry the fire, and must be restricted to the period when most seedlings have not initiated height growth. Management guidelines for fire-use in brownspot infected stands have been summarized by Boyer (1974), Croker (1975), and Maple (1976).

Annosus Root Rot

Research by Froelich, Hodges, and Sackett (1978) supports earlier evidence (Froelich and Dell 1967) that prescribed burning reduces severity of annosus root rot *(Heterobasidion annosum)* in the Southern United States. The experimental approach was to use prescribed fire as a prethinning treatment to prevent disease. In most cases, stand infections begin in forests when airborne spores germinate on the surfaces of fresh stumps; the fungus then spreads to stump roots and roots of adjacent trees where it causes growth loss or death. Although prescribed fire was not completely effective in preventing root rot, differences in infection have been very significant in some tests, particularly when the fungus was artifically introduced into all fresh stumps when trees were cut down. Although stump treatments, like borax, are more effective than fire, burning should have practical application in situations where chemicals have been difficult to justify economically. There is no evidence that fire will reduce further losses in previously infected forests, but by destroying sporophores and eliminating the litter and duff necessary for further development, prescribed burning of infected stands may be an effective treatment for reducing levels of inoculum in forests.

Fusiform Rust

Fusiform rust *(Cronartium quercuum* f. sp. *fusiforme)*, regarded as the most serious disease of southern pine, has become increasingly important over the last 30 years. This increase can be attributed to many factors. Most important is the planting of highly susceptible, fast growing, loblolly *(Pinus taeda)* and slash *(Pinus elliottii* var. *elliottii)* pines, particularly on sites formerly occupied by rust-resistant longleaf pine. The effect of fire on the disease is not certain because pine plantation management and fire control have gone hand-in-hand. The increase in oaks, an alternate host for the disease, that has occured due to fire control may have some bearing on the current incidence of the disease. However, using prescribed fire to reduce oak populations seems unlikely in the South because the small private ownership patterns make effective burning program impractical. This is further compounded by apparent long distance spread of the fungus and the tendency of oaks to sprout readily following burning. Compensating for any reduction in oaks is the increased infection of fire-induced sprouts. For example, in south Mississippi, red oaks *(Quercus falcata)* are normally resistant to disease, but heavy infection has been observed on succulent fire sprouts. Fire probably can be used as a therapeutic treatment in infected sapling pine stands, but only when the infections are confined to branches that can be pruned by fire. Since loblolly, and slash pine saplings are easily killed by moderate to intense heat, prescribed burning probably must be limited to precise conditions that result in moderate scorch of only the lower one-third to one-half of the live crown.

Dwarf Mistletoe

The interrelationships between fire and dwarf mistletoe *(Arceuthobium douglasii)* and research needs in this area have been summarized by Alexander and Hawksworth (1975). Although wildfire may have a sanitizing effect on forests by destroying infected trees and branches, the overall effect is likely to encourage disease by converting forests to mistletoe-susceptible seral types. Also, by being nonselective, wildfire may interfere with development of natural resistance; resistant types may be eliminated before they have a chance to propogate themselves. Current research emphasis is on the use of prescribed fire as a means of sanitizing and reducing the rate of spread in conifer forests.

Decay in Southern Hardwoods

While fire has been used to kill fire-intolerant hardwoods, the major effect is to cause fire scars, which provide infection access for wood decay fungi that rot the valuable lower stem segments of trees. The most thorough early assessments of loss from fire-induced butt rots were by Kaufert (1933) and Hepting (1935). In a more recent evaluation (Toole 1959), about 40 percent of all trees (obvious culls excluded) had butt decay; 84 percent of such decay was associated with fire scars. These percentages probably have not changed significantly even though the incidence of fire has decreased with more effective fire control. Because of the extreme intolerance of southern hardwoods to intense heat, wildfire must be controlled through the entire rotation period to prevent losses from fire-induced butt rots. Defective pines usually have commercial value and are systematically removed during intermediate or final harvests, but cull hardwoods often are ignored during logging. Consequently, a significant amount of growing space has been occupied by such trees decade after decade.

Beneficial and Harmful Effects of Fire

Known or possible beneficial and harmful effects of fire are shown in the following tables and are drawn from Parmeter (1977) (table 10 and 11).

Table 10.—*Known or possible beneficial effects of fire*

Effects	*Examples*
Sanitizes and eradicates disease by lethal fire temperatures.	Brown-spot needle blight of longleaf pine.
	Trees and branches infected with dwarf mistletoe.
	Possible pruning of branch galls of fusiform rust infected trees.
Effect on inoculum.	Elimination of litter and duff layer usually prevents sporulation by annosus root rot fungus. Sporophores killed by burning or disappear after burning.
	Reduces sporulation of some butt rot fungi.
	Reduces inoculum of brown-spot fungus.
	By killing galls of fusiform rust, fire may reduce aeciospore inoculum (effect likely to be minimal).
	Fire may reduce leaf spots that overwinter on the forest floor.
	Destruction of litter and duff eliminates habitat for dampening-off fungi.
	No significiant reduction noted on inoculum of *Porii werii.*
Destroys insect vectors of disease.	Destroys eggs of insect transmitting blueberry stunt virus.
Alters physical or chemical properties of soil or populations of soil- and root-inhabiting micro-organisms.	Incidence and spread of annosus root rot prevented in the Southern United States.
	Fire generally has a short-term effect on soil microorganisms that varies with fire intensity.
Inhibiting effect of smoke.	In laboratory tests, smoke affects spore germination, but the practical effects on forests may be small because of the infrequency of burning.

Table 11.—*Known or possible harmful effects of fire*

Effects	*Examples*
Stimulates spore germination, fungus growth, and fruiting (especially ascomycetes).	*Rhizinia undulata* attacks conifer seedlings planted in burned areas.
Intense heat causes fire scars.	Often results in butt rot, especially in hardwood forests of the Southern United States.
Fire or long-term fire suppression may lead to development of pure stands often more susceptible to pathogens.	Intense fire leads to development of pure seral forests susceptible to dwarf mistletoe. *Verticicladiella wagenerii* occurs in pure stands of ponderosa pine. Pure stands of Douglas-fir resulting from wildfire are susceptible to *Porii werii* root rot. Fire exclusion in Yosemite Valley has resulted in pure stands of ponderosa pine that are heavily damaged by annosus root rot.
Fire of fire exclusion may lead to buildup of alternate hosts of disease; fire may increase succulence of host tissue and increase susceptibility to disease.	*Ribes species*, hosts of white pine blister rust, increase after burning. When burning promotes development of succulent needle tissues, fusiform rust may increase. Oak sprouts following winter fire may be more susceptible to fusiform rust. Increases in powdery mildew on coyote bush.
Interferes with evolution of resistance in plants.	By being nonselective, wildfire destroys resistant trees before they disseminate genes for resistance.
Smoke injury.	May wound leaves and provide infection courts for microorganisms.

SUMMARY AND RECOMMENDATIONS

In an area as large as the United States, topography, climate, and plant communities vary greatly. Further, the natural frequency and intensity of fire has varied in various plant communities. It is for this reason that this state-of-knowledge review has been organized by major flora types representing various geographic regions. Fire frequency and intensity has been an important factor affecting flora. Fire is one of the most dramatic natural forces of plant communities over time. While some species or communities flourish following fire, other plants are curtailed or eliminated by fire. We have then either a most powerful tool or a significant damaging agent depending upon species response and what society wants.

Information on the effects of fire on flora is particularly important because of the importance of vegetation in considering any of the other effects of fire such as on fauna, soils, fuels, and hydrology. Vegetation is the key to many uses of forest and rangelands.

Our understanding of the role of fire in shaping plant communities is not totally lacking; the length of this report attests to that fact. However, each section of this report has pointed out major gaps in our knowledge. These gaps are summarized here to gain perspective on the problem from a national viewpoint.

CONIFEROUS FORESTS

North Pacific Maritime Forests

We need:

- Studies on long-term effects of prescribed burning and wildfires, particularly effects on nutrient cycling and site productivity.
- More knowledge comparing the effects of using fire to its alternatives on logged areas.
- More detailed knowledge of fire history and the natural role of fire in relation to each of the maritime forest types, particularly the role of shrub fields in the ecology of the maritime forests.
- Quantification of succession of vegetation and fuels after fire in all forest types.
- To apply our knowledge of fire's role in residue cycling to fuel management practices.

Forests of the Rocky Mountain West

We need:

- Better prescriptions on how to use fire, particularly for burning under trees where fuels have accumulated or are "laddered" and where fire must be used under conditions where there is high risk of losing a fire.
- Studies to refine our knowledge of using fire in climax ponderosa pine and Douglas-fir to develop how-to-do-it guidelines in using fire to meet land management objectives.
- To understand the role of fire in cool, temperate forests such as spruce and fir and to develop guides for using fire in these forests, particulary on how to burn when prescription conditions are limited. More information is needed on responses of particular species and succession of plant communities. We need to learn how to use fire to manipulate vegetation for a variety of reasons: wildlife habitat improvement, establishing natural vegetative patterns in wilderness and other reserves, and reducing competition for tree seedlings.
- More information on the effects of fire on insect and disease populations and how fire is involved in developing management strategies to alleviate insect and disease problems.

Sierra Coniferous Forests

We need:

- Better quantification of plant succession following disturbance by fire.
- Specific information on the relative fire and shade tolerance of various species.
- Information on the interrelationships of fire with insects and disease populations.

Northern Boreal Forests

We need:

- Information on the response of shrubs to fire, particularly information to improve predictions using preburn measurements.
- Fire effects research in Alaska concentrating on changes caused by fire in the organic forest floor and the conditions leading to those changes. We need to better predict reduction of soil organic layers due to fire.
- Better predictions of damage to trees, shrubs, forbs, grasses, mosses, and lichens.
- Carefully conducted, experimental prescribed fires using preburn inventories, documented records of burning conditions, and long-term monitoring to study the differential effects of fire on Alaska's flora over time.

Southern Pine Forests

We need:

- Better information on the effects of fire on lesser vegetation, especially the less common and rare and endangered species.
- Better information on the effects of fire on associated hardwood species.
- Information on the long-term effects of fire, including successional changes due to fire.

Northeastern Coniferous Forests

We need:

- A comprehensive review of applicable knowledge.
- To assemble information into planning and operational guides.
- Information on postfire response for entire plant communities.
- The capability to predict effects of fire using fire behavior or fire danger rating variables.
- Guides for planning the use of fire in wilderness areas.

DECIDUOUS FORESTS

Eastern Deciduous Forests

We need:

- A thorough review of applicable knowledge.
- To assemble available information into planning and operational guides.
- Better information on postfire response of entire vegetation communities.
- To establish relationships of vegetation response to fire characteristics, to fuel variables, and to fire danger ratings.

Southern Bottomland Forests

- We need basic information on the effects of fire in bottomland forests.

WOODLANDS AND CHAPARRAL

Pinyon-Juniper Woodlands

We need:

- Better prescription techniques to burn pinyon-juniper communities, particularly to avoid escape fires. Pinyon-juniper communities burn only under severe conditions.
- Information on successional development in pinyon-juniper communities following fires of known characteristics.

Western Oak Woodlands

- We need details on effects of fire on floristic composition, stand structure, and successional trends.

Sclerophyllous Hardwoods

We need:

- To develop cost-effective control strategies in chaparral communities.
- Better information on the successional response to fire.
- Information on the ability of fires to spread in various age classes.
- Research on determining the environmental conditions for prescribed burning.

NONFOREST AREAS

Desert

- We need better information on the use of fire to prevent the invasion of woody plants into grasslands.

Prairie Grasslands

We need:

- Definitive studies on the response of complex plant succession to fire.
- Studies of fire effects in grasslands with known fire characteristics.
- State-of-knowledge reviews for specific vegetation communities.

Sagebrush-Grasslands

We need:

- Better information on when prescribed burning can be conducted without favoring cheatgrass.
- Work on how fire intensity, season of burn, plant phenology, and soil and fuel moisture affect vegetation response.
- More information on writing prescriptions to achieve specific management objectives.

Insects and Disease

Although not covered in this report except in the invited papers, the fact that the relationships between insects, disease, and fire have not been generally addressed points out the need to define them better. Management of ecosystems, as such, demands that we link insects, disease, and fire. Historically, they have been grouped together as forest protection and studied as separate entities. We have seldom conducted our protection research in an integrated, multidisciplinary manner. Harvey, Larsen, and Jurgensen's paper on forest soils was included to show the significance of studying relationships among fire, vegetation response, and soil microorganisms. Their work is illustrative of the kinds of research needed to truly look at the entire ecosystem response to fire.

Froelich's section on disease emphasizes the same point. We have a dearth of information on fire-disease interactions. Yet, enough evidence exists to demonstrate that there is a great potential payoff in studying the dynamics of fire and diseases.

AN OVERVIEW

When results are compared across many vegetation types, we can see some general needs. The committee assembled this information and, while at the Denver meeting, we compared notes and agreed upon the following top priority needs across the Nation:

1. We need to assemble existing information on the effects of fire on flora into *state-of-knowledge management guides.* The publication of this report is a first step in this process. We now need to take information on specific plants and write prescribed burning guides to achieve land management objectives. Under revised fire management policies, this information is needed not only to use fire as a management tool, but also to assist in the establishment of appropriate levels of protection. An example of the type of summary needed is "Fire Ecology of Lolo National Forest Habit Types" (Davis et al. 1980).

2. A need frequently listed for many vegetation types is to *study successional trends following fire* and the roles individual species play in this development. This information becomes particularly important when writing prescriptions to achieve a variety of land management objectives.

3. Finally, there is great need to conduct *studies in fire effects with known fire characteristics.* Much of the information gathered in this report was the result of studies where specific fire characteristics were not known. Research in this area is badly needed.

A FINAL NOTE ON THE EFFECTIVENESS OF FIRE IN ALTERING PLANT COMMUNITIES

Intense fires are quite effective in either completely removing the existing plant community or in greatly reducing the population of individual species. Generally, this disturbance creates conditions for the establishment of seral species at the expense of climax species. Therefore, the potential for manipulating plant communities is greatest following intense and/or lingering fires. Less intense fires affect climax species in a lesser manner. However, plants differ in their tolerance for a particular intensity burn. This is the essence of why we need more fire effects research with carefully designed and conducted experiments. We need to relate more definitive fire characteristics and/or burning conditions to the entire ecosystem response over time.

Fire has been and still is an important factor in shaping the mosaic of plant communities in the United States. From a suppression standpoint, the three most costly fires in the past 20 years occurred on Alaska's Kenai Peninsula, the Upper Peninsula of Michigan, and the central coast of California. Despite these recent losses, annual acres burned have decreased significantly. We now have more than a billion acres of forest and rangeland in the United States under some form of organized protection. This protection may or may not influence the accumulation of forest and rangeland fuels.

In the absence of disturbances, biomass generally increases with time as a result of perpetual photosynthesis. Forest and rangeland fuel is organic matter that burns. The amount of vegetation available for combustion depends upon many factors such as fuel size, moisture content, and arrangement. There factors are affected by many events occurring throughout the history of the stands involved. Fire is certainly one of these and is discussed more fully in a companion paper entitled the Effects of Fire on Fuels (Martin et al, 1979). However, fuel accumulation is impacted greatly by other causes of mortality such as insects, diseases, suppression, natural thinning, wind, and snow damage. The activities of people and the role of decay are still other factors to consider. These factors all impact fuels in varying degrees and at varying points in the life of the stand.

A commonly espoused notion that fuels accumulate over time creating ever increasing fire hazards has yet to be proven. On the contrary, a recent study by Brown and See (1980) did not find any such relationship for the Northern Rocky Mountains. Mortality and downfall can occur at all stand ages. Fuel succession is complex. We must be wary of generalizations that oversimplify this process. Certainly, more research is needed to study succession following distrubances and the dynamic aspects of fuels. Human land-use activities have also made a major contribution to the fuel hazard. When we grow and harvest forest vegetation, we must be prepared to manage the fuel situation we create.

Some consequences are:

1. Fires burn more than 2.5 million acres per year for all acres protected.
2. Vegetation succession is changing and the mix of species of aethetic and economic importance is greatly affected.
3. Fuel characteristics change dramatically and irregularly and fuel hazard is often high.
4. Extensive areas of forest (particularly in the West) contain hazardous fuel conditions resulting from insects, disease, altered fire cycles, and the activities of human beings. In some cases, management is limited because of high fuel hazards.

Two useful methods to correct fuel hazard conditions are prescribed fires where fires are purposely set under reasonably safe conditions and a new policy that allows certain wildfires to burn under a prescribed set of conditions.

Essentially the ecological response of plant species, the level and effectiveness of fire protection, and the use of fire as a management tool all have a major effect on the productivity of the land and the kinds of goods and services that the land manager is able to produce. Crucial to the entire process is an understanding by the manager of the effects of fire on flora.

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